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NEL REPORT 1158

# THE PROBLEM

Develop a measuring device capable of recording the radio field intensity of the Omega navigation stations or of similar long-range, vlf systems.

# RESULTS

1. A field strength recorder was developed to operate as a superheterodyne receiver with three channels of manual gain control, an i-f filter with a narrow bandwidth, a coherent detector, and three recorders (one for each Omega station).

2. Six recorders have been constructed and are installed at RADC, Rome, New York; USNRS, Farfan, C. Z.; USNRS(R), Wahiawa, Oahu, Hawaii; University of Alaska; NAS, Whidbey Island, Washington; and at the Navy Electronics Laboratory, San Diego, California. These sets are currently being used to evaluate the radio field coverage of the Omega transmitting stations. Subsequent reports will give the results of the evaluation.

# RECOMMENDATION

Consider the field strength recorder, in its present design, adequate for measuring the radio field coverage of the Omega system and for use in other studies of vlf radio propagation.

# ADMINISTRATIVE INFORMATION

Work was performed under SS 161 001, Task 6101 (NEL A1-4) from April 1961 to March 1962. The report was approved for publication 11 February 1963.

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# INTRODUCTION

Omega, a long-range, vlf hyperbolic navigation system, is currently undergoing a program of evaluation and data-taking to determine propagation times, diurnal propagation time changes, and the coverage area of the system. The AN/URN-18(XN-1) Navigational Set, Omega, and the AN/WRN-2(XN-1) Navigational Set, Omega, are being used to measure the propagation times and diurnal changes in order to prepare navigational charts and tables.

Measuring the coverage area of the three Omega stations is not possible, however, with ordinary radio field intensity measuring equipment. All three stations operate in an extremely poor signal-to-noise environment, on the same frequency (10.2 kc/s), and transmit sequentially in short bursts. Even if the individual stations were allowed to transmit for longer periods, their signals range from a maximum of approximately 100 mv per meter, near the transmitting sites, to values many times below the atmospheric noise in a nominal 100-c/s bandwidth.

Within the limits of these special conditions, the field strength recorder to be described here was developed. Six recorders have been constructed and are now in use to evaluate the radio field coverage of the Omega stations. A set of sample field intensity recordings is given in the Appendix.

# DESIGN REQUIREMENTS

It was established that the proposed Field Strength Recorder should be capable of: (1) identifying which signal was being received; (2) detecting the amplitude of each signal without detecting noise; and (3) storing and recording each signal without degradation caused by its duty cycle.

The AN/URN-18(XN-1) and AN/WRN-2(XN-1) navigational sets were evaluated to determine their suitability for operating the recorder, which would have to operate as an auxiliary unit coupled to existing navigational equipment.

The AN/WRN-2(XN-1) was found unsatisfactory for use with a field intensity recorder because of its input circuitry, which did not allow for easy coupling with an auxiliary piece of equipment.

Evaluation of the AN/URN-18(XN-1), however, showed that this equipment offered several features which would make it entirely satisfactory for use with the recorder under development. The most important of these features were:

1. It contains a keying generator (commutator) producing waveforms which are maintained in synchronism with the transmitted signals. This performs the identification necessary to sort out the signals and place the results in the proper channel.

2. It has a stable oscillator and a radio frequency generator which is used as a local oscillator.

3. It has a reference frequency generator which is held in quadrature with the transmitted signals from each station.

4. The first rf amplifier stage operates linearly and has an input filter with a bandwidth of approximately 100 c/s.

The characteristics listed above would permit design of a field strength recorder which would operate as a superheterodyne receiver with three channels of manual gain control, an i-f filter with a narrow bandwidth, a coherent detector, and three recorders (one for each OMEGA station). The AN/URN-18(XN-1) offered the additional advantage of sufficient power supply reserve to operate the recorder without a separate power supply.

Table 1 shows the outputs from the AN/URN-18(XN-1) required to operate the field strength recorder, and their end use:

Table 1. Outputs from AN/URN-18(XN-1) required to operate field strength recorder.

| OUTPUT | FUNCTION |
|---|---|
| 1. 115 vac | Provides heater power, drives recorders and cooling fan. |
| 2. +300 vdc | Provides dc power to operate all amplifier tubes. |
| 3. Long keying pulses corresponding to Channels 1, 2, and 3 | Switches the appropriate rf attenuator used for manual gain control. |
| 4. Short keying pulses corresponding to Channels 1, 2, and 3 | Switches the output of the "In-Phase Detector" to the appropriate recorder channel. |
| 5. RF Signal | Provides an amplified carrier signal from the antenna. |
| 6. Local oscillator | Provides a frequency for use in the balanced modulator, corresponding to local oscillator injection, to produce a 1.8 kc/s i-f. |
| 7. Reference | Provides a reference frequency of 1.8 kc/s for each channel of operation. Each reference is held at a constant phase angle to the i-f of the signal received in each channel. These references are switched, sequentially, by the AN/URN(XN-1) in synchronism with the received signals. |

A full description of the outputs from the AN/URN-18 (XN-1), and how they are derived, is contained in the governing technical manual.[1]

Figures 1-8 are various views of the field strength recorder and of the AN/URN-18 Navigational Set.

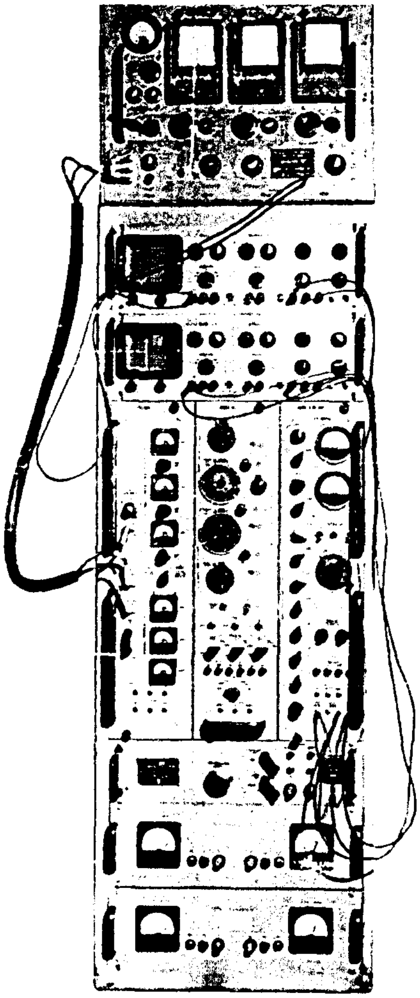

*Figure 1. Field Strength Recorder mounted on AN/URN-18 (XN-1).*

[1] Bureau of Ships NAVSHIPS 94114, Technical Manual for Omega Navigational Set, Type 1, AN/URN-18(XN-1), 31 May 1961

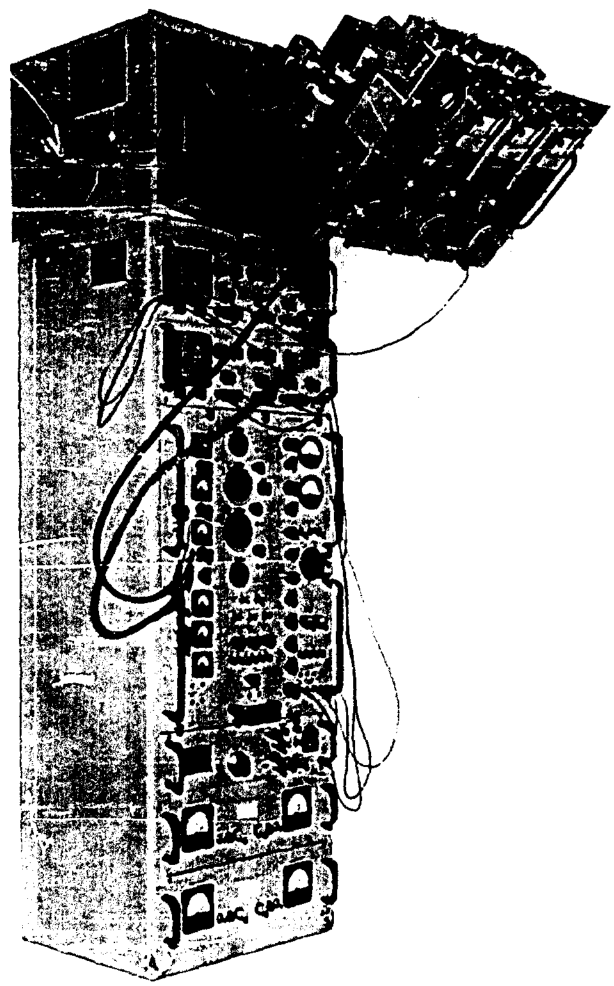

*Figure 2. Field Strength Recorder mounted on AN/URN-18(XN-1), with drawer pulled out.*

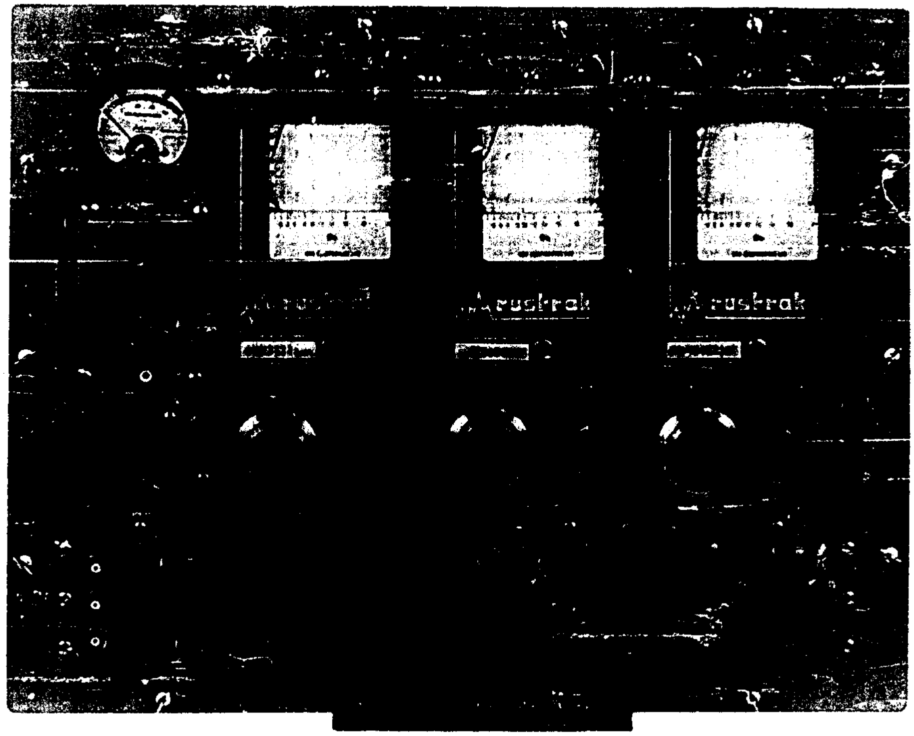


*Figure 3. Front view of Field Strength Recorder.*

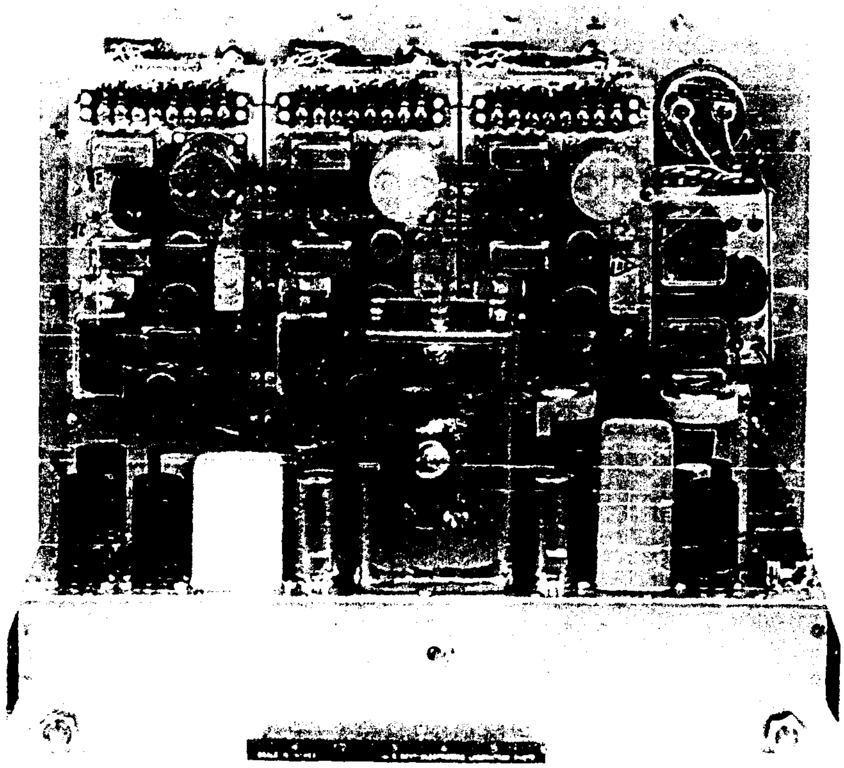

*Figure 4. Rear interior view of Field Strength Recorder.*

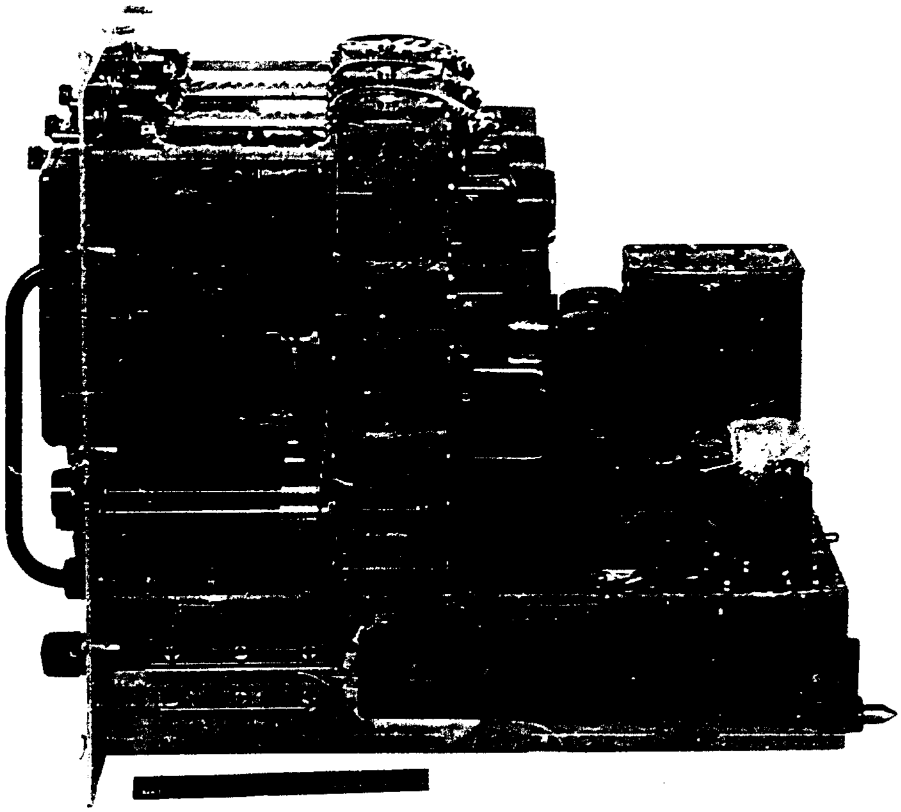

*Figure 5. Right side of Field Strength Recorder.*

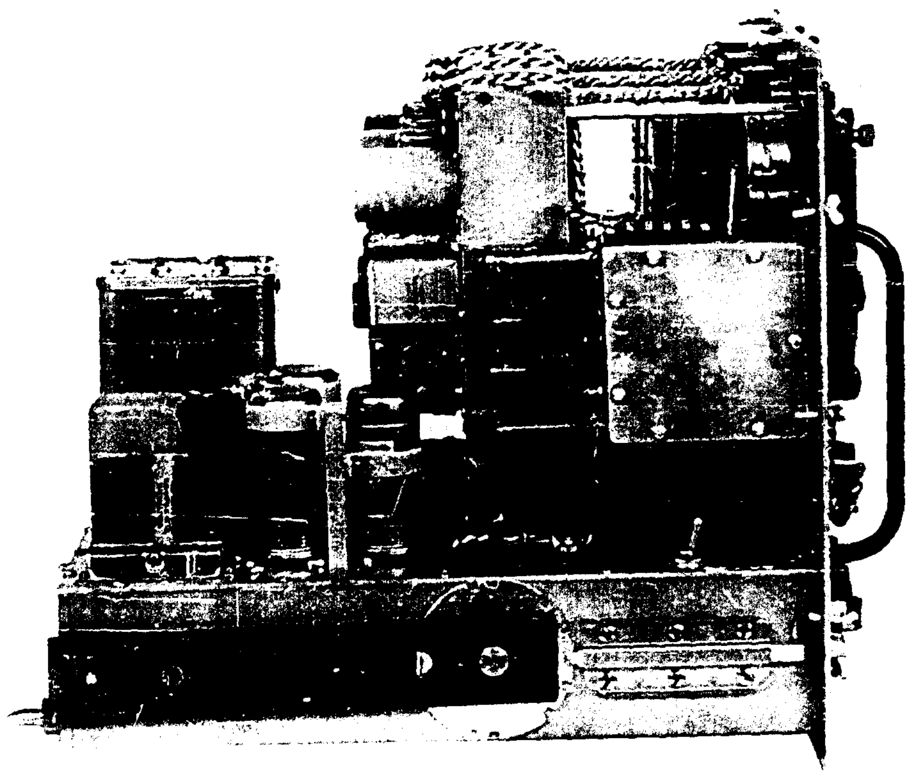

*Figure 6. Left side of Field Strength Recorder.*

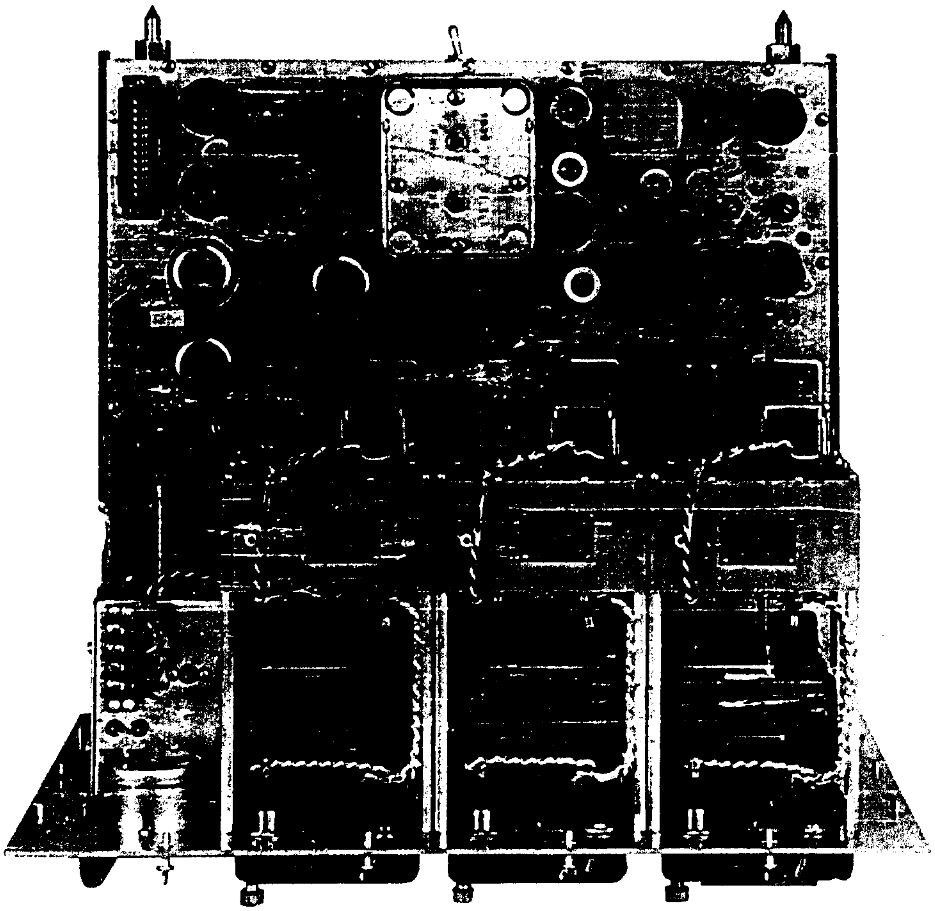

*Figure 7. Top interior view of Field Strength Recorder.*

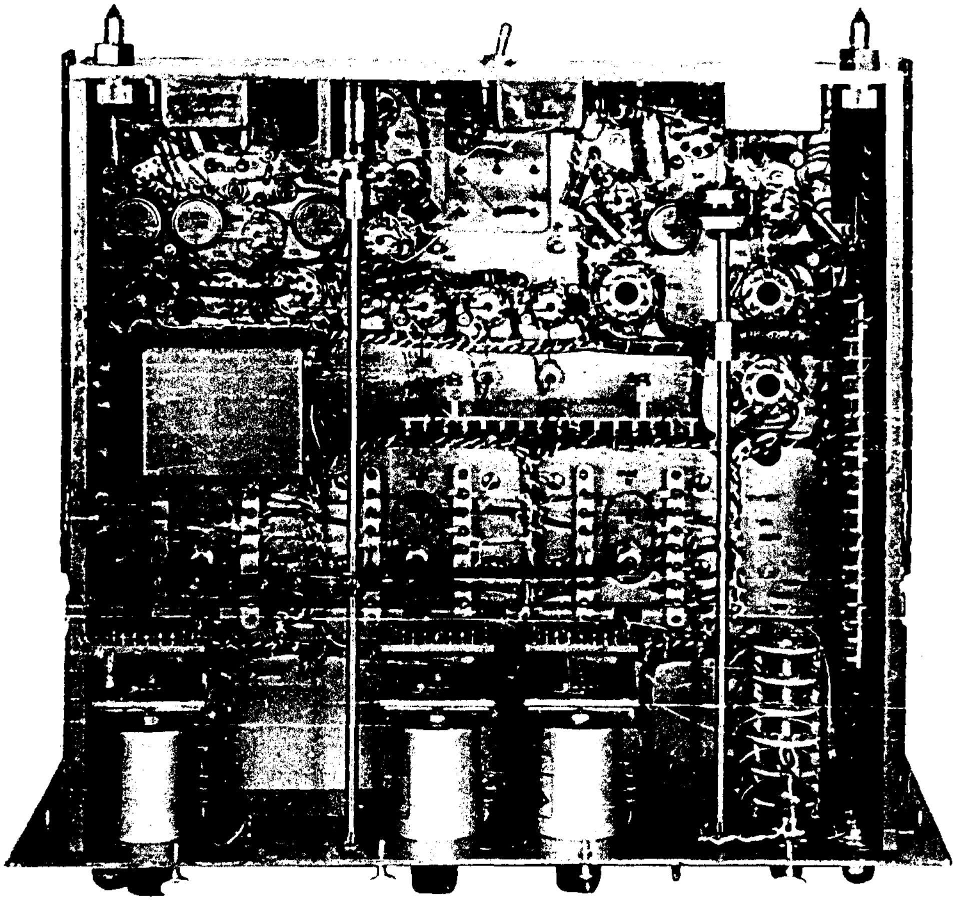

*Figure 8. Bottom interior view of Field Strength Recorder.*

# PRINCIPLES OF OPERATION

## Transmitted Signals and Relation of Keying Signals Generated by the AN URN-18(XN-1)

The transmission pattern has been established for operation of the Omega network and is not likely to change during the period of evaluation.

The relationship shown (fig. 9) for the four transmission segments was arranged for optimum effectiveness of the system. The product of the radiated power and information rate of the Omega stations dictated the assignment of transmission segments to them. Forestport, being the weakest station, is given two bits of information during each cycle of transmission. The choice of segment (A, B, C, or D) to be placed in each channel is made completely flexible by choice of selector switches on the front panel of the AN/URN-18(XN-1). System use, however, dictates the placement of segment D in Channel 2. Segments A or C, or A and C may be placed in Channel 1 or Channel 3, and Segment B may be placed in the remaining channel. Any, or all, segments may be turned OFF, thereby losing the corresponding bit of information. Operation of a segment switch automatically changes the keying generator outputs to both the AN/URN-18(XN-1) and the field strength recorder.

The three recorders are arranged on the front panel, with all of the appropriate switches, attenuators, and controls directly beneath them. The attenuators (manual RF GAIN) are identified as Channels 1, 2, and 3. Whatever segment has been placed in Channel 1 of the AN/URN-18(XN-1) is also placed on the Channel 1 recorder. This also applies to Channels 2 and 3.

The transmission pattern (fig. 9) shows that the Long segments turn ON 0.1 second <u>before</u> and turn OFF 0.1 second <u>after</u> each transmitted segment is received. This allows the appropriate attenuator to be switched into the

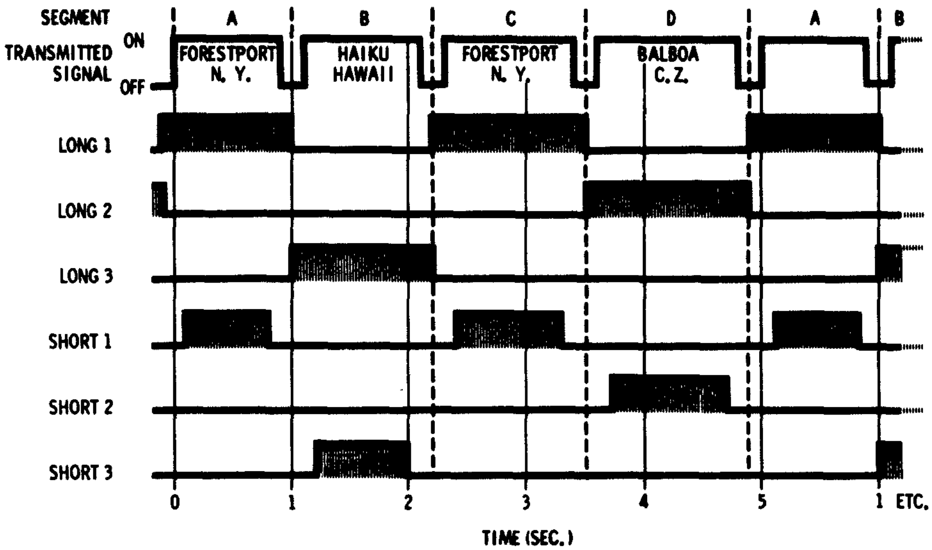


*Figure 9. Keying pattern of Omega system.*

circuit before and out of the circuit after the transmitted signal is received. The Short segments turn ON 0.1 second after the start and turn OFF 0.1 second before the end of each transmitted segment. The Short segments, which switch information to the recorders, thus insure that something is being received during their closing time. Therefore, these overlapping and underlapping keying signals allow for some misalignment of the keying pattern to the received signals with no degradation of the recorded values.

# CIRCUIT DESCRIPTION

## Switching Section

Each of the three relay control tubes, V-7A and B, V-8A and B, and V-9A and B performs identical functions, for Channels 1, 2, and 3 respectively, so only one, V-7, will be discussed.

The line marked LONG 1 comes from the keying generator (commutator) of the AN/URN-18(XN-1). The "OFF" voltage is approximately -9 vdc and the "ON" voltage is approximately -2.5 vdc.

Since V-7, a 12AT7WB, turns on most predictably with zero bias, the keying signal is inserted through one end of a voltage divider. The other end of the voltage divider is connected to +300 vdc. This raises the potential applied to $G_1$ of V-7A to a slightly positive value when the commutator produces LONG 1 "ON". The resistances are sufficiently high that the grid clamps this potential near zero (ground).

Variations in $G_m$ are effectively removed from affecting the current through V-7A leaving only a drop of emission to prevent the closing of K-1, the Channel 1 attenuator relay. When the commutator produces an "OFF" voltage, $G_1$ is driven sufficiently negative to cut off practically all current flow.

S1-2 causes relay K-1 to be operated by V-7A when in the "OPERATE" position. In all other positions of S1, K-1 is energized through a resistor to ground.

Note that K-2 and K-3 are operated by their respective tubes (V-8A and V-9A) when S1 is in the "OPERATE" position and are de-energized in all other positions. This means that in the "CALIBRATE" positions only the Channel 1 attenuator is in use.

The line marked SHORT 1 comes from a relay drive tube in the AN/URN-18(XN-1). The "OFF" voltage is approximately zero and the "ON" voltage is approximately +80 vdc. Relay K-4 requires 48 vdc to operate. In order to allow for degradation of tubes, 60 vdc is provided with new tubes. The 22-volt Zener diode, 1N1608A, has a dual purpose: (1) it provides a fixed voltage drop which applies the required voltage to the coil of K-4; and (2) it provides cutoff bias to the cathode of V-7B when the grid is at zero. It does this with such a small flow of current that the voltage drop across the 8000-ohm coil of K-4 is only a small fraction of a volt. This prevents any possible flow of current through insulation resistance between the coil and the normally open (N. O.) contacts of K-4. Several types of relays of various manufacturers were tried for use in K-4, K-5, and K-6. The Hart Type "S" relay had a measured insulation resistance from coil to N. O. contacts, coil to normally closed (N. C.) contacts, and N. O. contacts to ground of more than 50,000 megohms. An insulation resistance of 5000 megohms or less produces an inaccurate recording and none of the other relays tested offered consistently high enough insulation resistance to produce the desired accuracy. In the OPERATE position of S1, V-7B receives its control voltage from the line marked SHORT 1. In the three CALIBRATE positions of S1, V-7B receives its control voltage from a diode "OR" gate associated with S1-7, S1-8, and S1-9. In each of the three CALIBRATE positions, one channel is deleted. The reason for this will become clear during the discussion of the in-phase detector (p. 21 ). In the "SET REFERENCE AND BALANCE" position of S1, V-7B receives its control voltage from a voltage divider connected to +300 volts through switch S5. This places the grid of V-7B at approximately +82 vdc, actuating relay K-4. Switch S5 allows K-4 to be de-energized completely in the "SET REFERENCE AND BALANCE" position of S1. The utility of S5 will be explained in the section entitled "DC Amplifier and Recorder," p. 25 .

S1-10 supplies dc power to the calibration oscillator in all positions except "OPERATE."

S1-11 supplies dc power through a resistor to energize K-8 and K-9 in the three "CALIBRATE" positions.

S1-12 supplies dc power through a resistor to energize K-7 in the "SET REFERENCE AND BALANCE" position.

The function of K-7, K-8, and K-9 will be explained in the section on the "In-Phase Detector," p. 21 .

Switches S1-7, S1-8, and S1-9 and their associated diodes form a selective OR gate which allows the three relays, K-4, K-5, and K-6, to operate on two of the three available channels when S1 is in one of the three "CALIBRATE" positions.

## Local Oscillator

The local oscillator voltage is generated in the rf unit of the AN/URN-18(XN-1) and is delivered, through J2, to the field strength recorder at a level of approximately 30 volts P-P. The frequency is 1.8 kc/s higher than the received signal. Since the input level is higher than necessary for mixer operation the local oscillator amplifier, V-3, is connected as a cathode follower.

The output of V-3, at a level of 6 volts P-P, is delivered to the center tap of the secondary winding of T2. Here it becomes the carrier, or switching voltage, for the balanced modulator CR1.

## RF Amplifier

The rf amplifier consists of tubes V-1A, V-1B, V-2A and V-2B. The rf input signal enters through J1 from the first rf amplifier in the AN/URN-18(XN-1). The source impedance of the input is high, so V-1A is made a high input impedance cathode follower. This prevents loading of the rf amplifier in the AN/URN-18(XN-1). The low-impedance output of the cathode follower is a desirable source for feeding the potentiometer type attenuators.

Located between the output of V-1A and the input of V-1B are three attenuators, one for each channel, and three relays which select the attenuator to be used.

These relays are actuated by power from the switching section. Relay K-1 operates from a LONG 1 pulse inserting the Channel 1 attenuator; K-2 operates from a LONG 2 pulse inserting the Channel 2 attenuator and K-3 operates from a LONG 3 pulse inserting the Channel 3 attenuator.

During idle times all of the relays ground both the moving contact arms of the relays, minimizing the capacitive feedthrough of the signal across the normally open contacts of the relay.

The output side of relays K-1, K-2 and K-3 all go to the input of V-1B, which is a voltage amplifier. The output of V-1B goes to a potentiometer gain control. This is a front panel screwdriver adjustment which standardizes the gain of the first rf amplifier of the AN/URN-18(XN-1), V-1A, V-1B, V-2A and V-2B. V-2A is a voltage amplifier directly coupled to V-2B, a cathode follower, which drives the primary windings of T2. Here it becomes the modulating voltage of the balanced mixer CR1.

## Balanced Modulator and I-F Filter

Transformer T2, diode quad CR1, switch S7 and the primary of the i-f filter form a conventional balanced modulator which suppresses both carrier and modulation producing upper and lower sidebands. The i-f filter consists of a double-tuned, slightly over-coupled filter, tuned to 1.8 kc/s, which passes the lower sideband and rejects the upper sideband.

The 3-db bandwidth of this filter is 20 c/s. Temperature compensation is accomplished by the two 8200 μμfd N120 capacitors and tuning by the two 360 to 1000 μμfd trimming capacitors. Switch S7 inverts the i-f signal. This may be necessary to maintain the correct phase relationship between the signal and reference voltages when the field strength recorder is used with various AN/URN-18(XN-1) equipments. CR1 is an NEL-manufactured diode quad consisting of four 1N198 diodes mounted on a noval header and encapsulated to fit in a JAN type tube shield. The diodes are matched to within 2 per cent over a range of 0.5 to 30 milliamperes forward conduction at room temperature (approximately 27°C). No additional balancing of the modulator stage was found to be necessary. Most of the carrier and modulating voltages present due to imbalance are removed by the i-f filter, and the remainder does not affect the kind of detector in use.

## Signal Amplifier

The signal amplifier consists of a voltage amplifier, V-4A, and a cathode follower output stage V-4B. The input signal is taken from the center tap of the final tuned circuit of the i-f filter. Amplifier V-4A amplifies the signal and applies it to the signal gain control potentiometer which standardizes the gain of V-4A and V-4B. The output of the signal gain control goes to the input of a cathode follower which in turn applies the received i-f signal to the in-phase detector. A double coupling network was used to minimize direct current leakage from the cathode follower to the recorder dc amplifiers. Relay K-7 switches the signal input, to the in-phase detector, from the signal amplifier to ground. Relays K-8 and K-9 substitute the signal voltage for the reference voltage in the reference amplifier. The use of relays K-7, K-8, and K-9 will be covered in the section entitled "In-Phase Detector," page 21.

## Reference Amplifier

The reference amplifier input, J3, obtains its reference signal of 1.8 kc/s from the reference input to the phase detector in the AN/URN-18(XN-1). The AN/URN-18(XN-1) has three resolver phase shifters, one for each channel, which holds this reference signal at a constant phase difference from the signal in each channel. The relationship of the phase difference between the reference in the AN/URN-18

(XN-1) and signal in the Field Strength Recorder is unimportant, as long as it is a constant. This can be corrected by S7 (phase reversal of the signal) and the REFERENCE PHASE ADJUST potentiometer which allows almost 175 degrees of phase shift in the reference amplifier. The input stage of the reference amplifier (V-5A), is a constant-amplitude phase shifter which drives a voltage amplifier V-5B. The output of V-5B goes to reference gain control potentiometer which adjusts the level of the reference voltage at the in-phase detector, thereby compensating for changes in reference input voltage and changes in gain of V-5A, V-5B, V-6A and V-6B. The output of the reference gain control passes through relay K-8 to a voltage amplifier, V-6A, and a transformer drive stage, V-6B. T3 is a plate (10 kilohms) to line (1000 ohms) transformer with a carefully balanced, bifilar-wound, split secondary. This provides the switching voltage for the diodes of the in-phase (coherent) detector.

## In-Phase (Coherent) Detector

Reference or switching voltage is applied to the diode quad, CR2,* by the balanced secondary windings of T3. The signal voltage to be measured is applied to the center tap connections of the secondary windings. In this discussion, diodes 1-2 and 3-4 will be known as the series diodes. Diodes 6-7 and 8-9 will be known as the shunt diodes.

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*CR2 is an NEL-manufactured diode quad consisting of four 1N914B diodes mounted on a noval header and encapsulated to fit in a JAN type tube shield. The diodes are matched to better than 1 per cent over a range of 0.5 to 30 milliamperes forward conduction at temperatures of 30°C, 50°C and 70°C. The extremely high back resistance, in conjunction with a relatively low load resistance, makes balancing in the reverse direction unnecessary.

The actual in-phase detector consists of windings 3-4 and 5-6 of T3, diodes 1-2 and 3-4, the two 1-kilohm resistors, the 100-ohm balancing potentiometer and the 22 K load resistor from TP7 to ground.

A dc return from the detector is provided either by K-7 in the energized position or the 22 K load resistor of the signal amplifier if K-7 is de-energized. A simple analysis of the detector operation is achieved by considering the series diodes as switches. When the reference voltage is of the proper polarity for forward conduction of the series diodes, the switches are closed, allowing whatever signal is applied to the center tap of T3 to appear on the load resistor of the detector. Conversely, when the reference voltage is of the polarity for non-conduction of the series diodes, the switches are open and the signal applied to the center tap of the transformer cannot reach the load resistor. The shunting diodes and resistor load transformer T3 during the time that the series diodes are reverse biased. This causes a symmetrical waveform to exist at the REFERENCE T. P. and facilitates measuring the actual switching voltage present. The two 1-kilohm resistors and the 100-ohm, 10-turn, potentiometer form the detector balance network. With the function selector switch in the SET REFERENCE AND BALANCE position, only the reference switching voltage is present. The center tap of the detector transformer is grounded through K-7. The detector balance potentiometer is adjusted for the electrical midpoint of the transformer-resistor-diode network. This is evidenced by a reading of zero voltage, at the output of the detector, indicated on the recorders. With the function selector switch in the OPERATE position and the AN/URN-18(XN-1) in normal operation, tracking the phase of the received signals, an adjustment of the reference phase can be made. Correct adjustment will produce a symmetrical, positive-going, half-wave output from the detector as indicated on figure 10.

This output voltage, filtered by a suitable RC low-pass filter, becomes the measured field strength of the received signals.

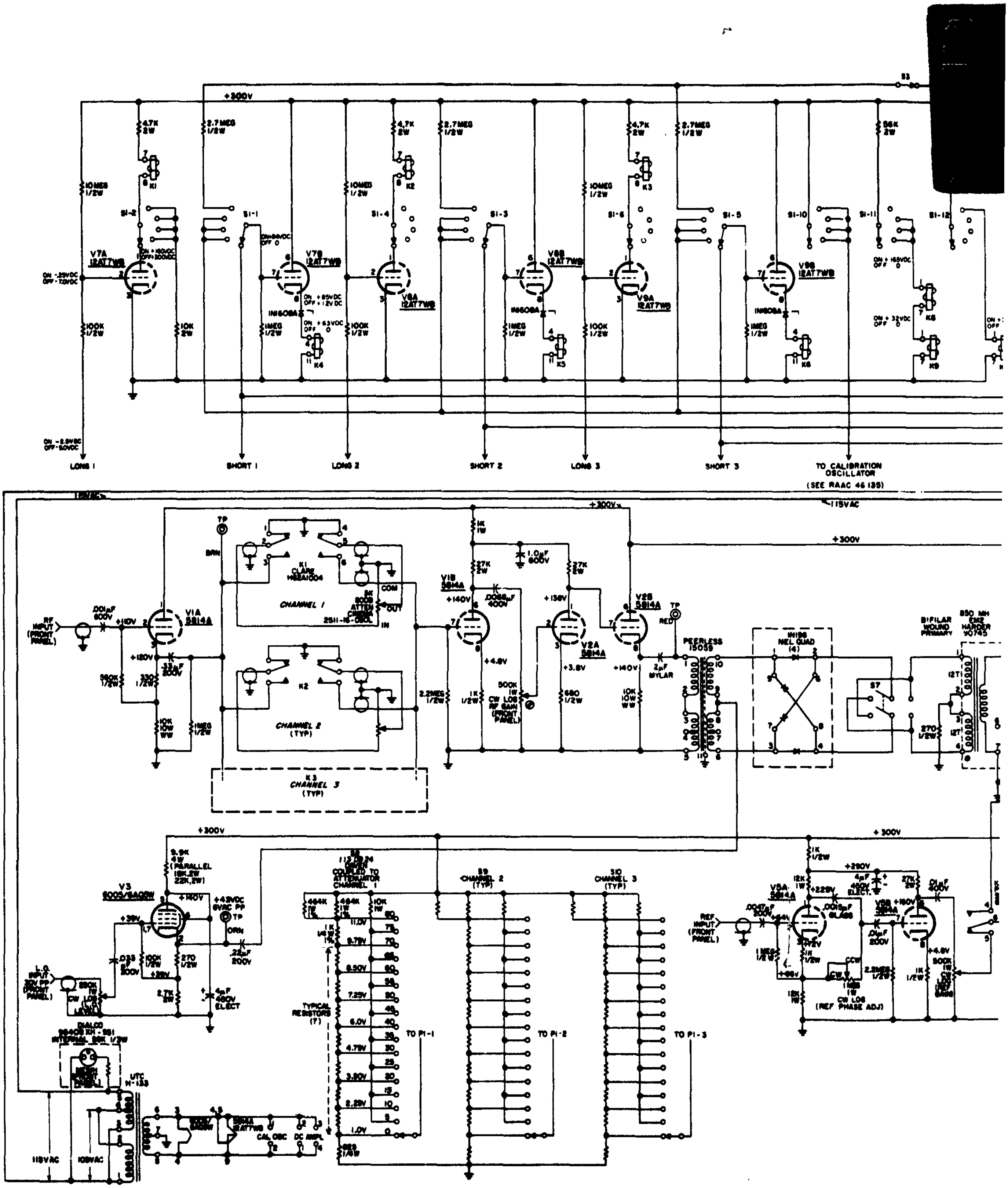
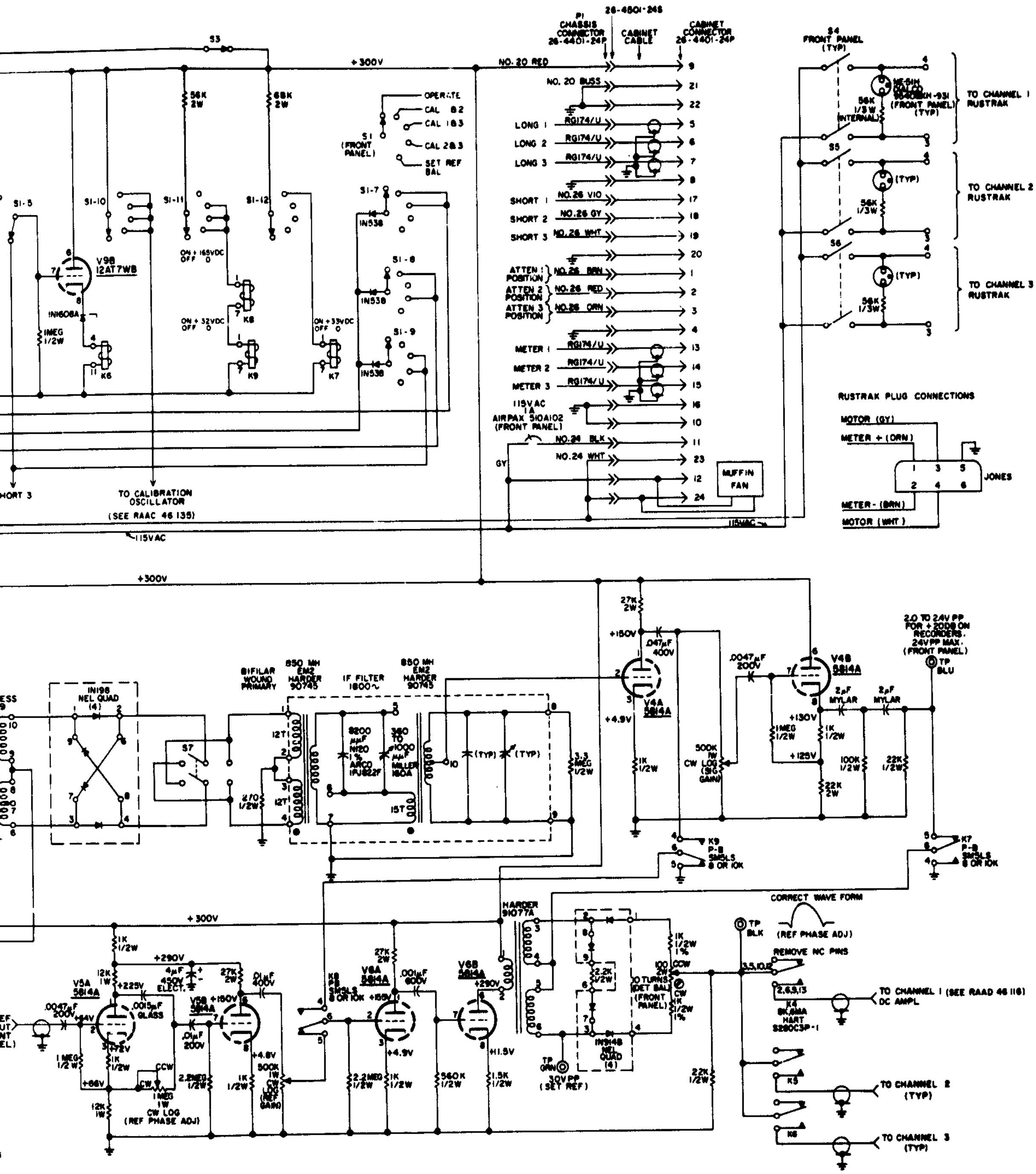



*Figure 10. Schematic diagram of Field Stre*

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c diagram of Field Strength Recorder.

During the calibration process, when noncoherent signals are being measured, it is necessary to convert the in-phase detector to a linear detector which is not phase sensitive. This is accomplished by diverting the signal voltage to the reference amplifier through relays K-8 and K-9. This signal voltage is introduced at the proper place in the reference amplifier to produce a positive dc output. The level of this reference voltage is many times larger than the voltage being measured; therefore, it alone controls the switching of the diodes. This, for all practical purposes, results in a linear detector that is not phase or frequency sensitive. The output of the in-phase detector is directed to the appropriate dc amplifier and recorder by K-4, K-5, and K-6. These relays are Hart "S" series which have a hermetically sealed coil inside the hermetically sealed can containing the contact assembly. The relays are in a four-pole, two-throw configuration. This is not necessary, but, since it is the only form available, all four poles were used. The normally open fixed contact connectors in the socket were removed to make connections easier, reduce the surface leakage paths and for spare parts.

## DC Amplifier and Recorder (fig. 11)

There are three dc amplifiers, and associated recorders, used in the Field Strength Recorder. One amplifier and recorder is provided for each of the three channels to be measured. The input of the dc amplifier consists of a low-pass filter (integrator) of four bandwidths expressed as an RC time constant in seconds and a switch which selects the bandwidth to be used. In addition to selecting the bandwidth, the selector switch has a position which shorts the input of the amplifier without removing the charge stored on the input filter capacitor and a position which grounds the capacitor and removes the charge stored on it.

The basic amplifier is ac-coupled with an input chopper to produce alternating voltage and a synchronous chopper rectifier at the output. The input chopper compares the voltage stored on the integration capacitor with the rectified output of the amplifier, converting this to an ac voltage necessary to cause the rectified output to closely follow the input voltage. The very high gain (approximately 110 db) of the ac amplifier insures that the input and output voltages are very close together. The effective input resistance of the dc amplifier is calculated from the time necessary to discharge the integration capacitor to 37 per cent of a charge stored on it when the input is disconnected from the source. Effective input resistance is approximately directly proportional to the product of the gain of the ac amplifier and the full scale sensitivity as set by the potentiometer in the feedback loop. A typical value of effective input resistance for an amplifier with new tubes and a full scale sensitivity of 1000 mv is approximately 9000 megohms. If the gain of the amplifier drops to one half, <u>or</u> if the full scale sensitivity is set to 500 mv, the effective input resistance will drop to approximately 4500 megohms.

Typically, the full scale sensitivity is set for 250 mv, allowing the gain of the amplifier to drop to half before tube replacement and giving an effective input resistance of from 2250 to 1125 megohms. This high effective input resistance insures that the recorded values will be within 1 per cent of the source voltage when the input duty cycle is reduced from 100 per cent in the CALIBRATE position, to 14 per cent as would be the case for Segment A, only, in one channel.

The two 10-megohm resistors connecting the armature to the fixed contacts of the chopper, G1, suppress transients developed during the transit time of the armature from one contact to the other. The output of the chopper is capacitively coupled to the amplifier since the entire chopper operates positive with respect to ground. The first stage

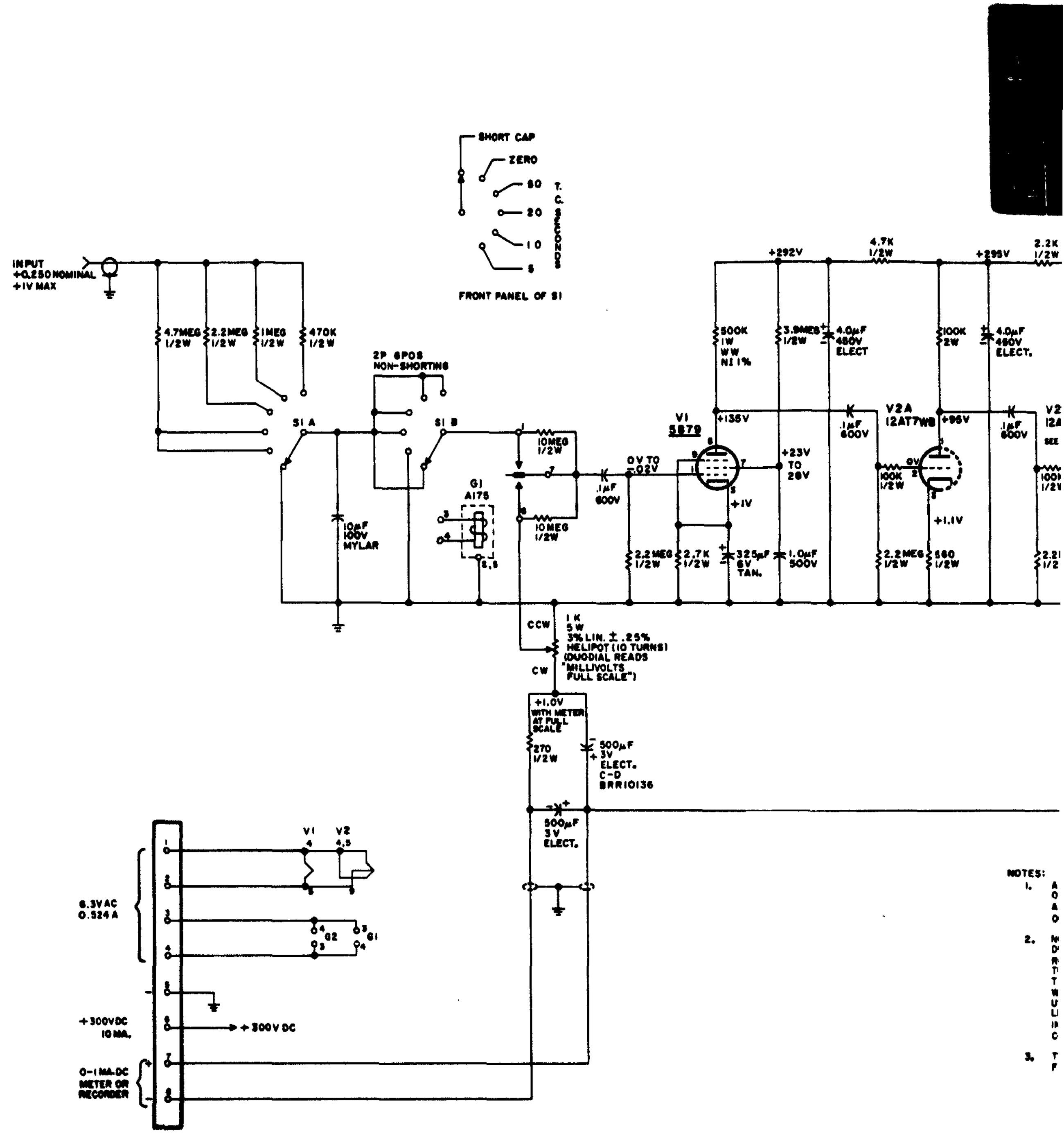
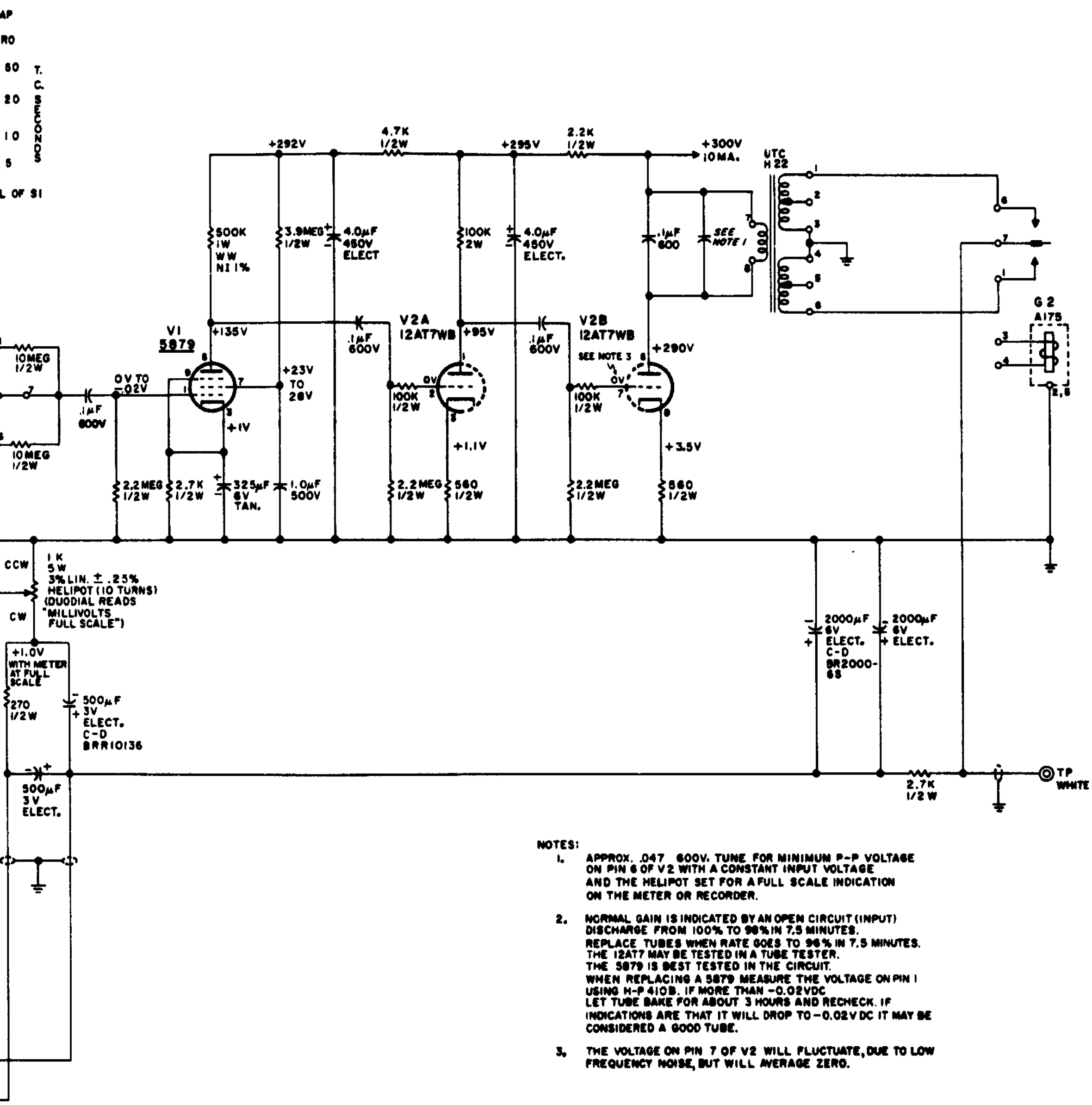



*Figure 11. Schematic diagram of dc amplifi*




NOTES:

1. APPROX. .047 600V. TUNE FOR MINIMUM P-P VOLTAGE ON PIN 6 OF V2 WITH A CONSTANT INPUT VOLTAGE AND THE HELIPOT SET FOR A FULL SCALE INDICATION ON THE METER OR RECORDER.

2. NORMAL GAIN IS INDICATED BY AN OPEN CIRCUIT (INPUT) DISCHARGE FROM 100% TO 98% IN 7.5 MINUTES. REPLACE TUBES WHEN RATE GOES TO 96% IN 7.5 MINUTES. THE 12AT7 MAY BE TESTED IN A TUBE TESTER. THE 5879 IS BEST TESTED IN THE CIRCUIT. WHEN REPLACING A 5879 MEASURE THE VOLTAGE ON PIN 1 USING H-P 410B. IF MORE THAN -0.02VDC LET TUBE BAKE FOR ABOUT 3 HOURS AND RECHECK. IF INDICATIONS ARE THAT IT WILL DROP TO -0.02V DC IT MAY BE CONSIDERED A GOOD TUBE.

3. THE VOLTAGE ON PIN 7 OF V2 WILL FLUCTUATE, DUE TO LOW FREQUENCY NOISE, BUT WILL AVERAGE ZERO.

*e 11. Schematic diagram of dc amplifier.*

is a low-noise pentode operating at maximum gain commensurate with stability and interchangeability of tubes. Some new tubes exhibit a "gassy" characteristic immediately after being placed in operation.

This is evidenced by a negative voltage appearing on $G_1$. A few hours of operation will usually correct this condition and the stage will then operate at full gain. The voltage gain of the V-1 stage is approximately 200.

Tube V-2 is a 12AT7WB. The first half is a conventional RC coupled voltage amplifier. The second half is a power amplifier with appreciable voltage gain. The primary winding of the H-22 output transformer is tuned to adjust for zero phase shift from input to output chopper. Proper adjustment is indicated by a minimum ac voltage across either the primary or secondary while a constant input voltage is held. The split secondary winding is connected to the output chopper, G2, operating as a synchronous full-wave rectifier. The dc output of the rectifier is filtered by a single-section RC filter consisting of 2.7 kilohms and 4000 μf. A multiple-section filter was avoided, since phase shifts in excess of 90° produce positive feedback. The dc from the filter passes through the 1-milliampere meter movement, the metering filter and the 1-kilohm, 10-turn helipot. This feedback loop provides the voltage to be compared with the input voltage and is adjusted by the helipot. Since a 1-milliampere current is required for a full scale indication on the meter, it is obvious that zero to 1 volt is available on the arm of the helipot while the meter is indicating full scale. Since the amplifier causes the feedback voltage to closely follow the input voltage, it is now apparent that the full scale sensitivity is set by the position, and therefore the voltage, of the helipot arm. The two-section metering filter, consisting of two 500-μfd capacitors, the meter movement, and a 270-ohm resistor, is returned to the high side of the rectifier filter and introduces no additional lag to the feedback voltage. This filter removes induced 60-c/s hum from the recorder drive motor and transients caused by the recorder striker which will cause the meter to read erroneously and erratically.

## Calibration Oscillator (fig. 12)

In order to standardize the gain, from the first tuned rf circuit of the AN/URN-18(XN-1) to the recorder reading, it is necessary to inject a signal of known amplitude and frequency into the first tuned circuit of the AN/URN-18 (XN-1).

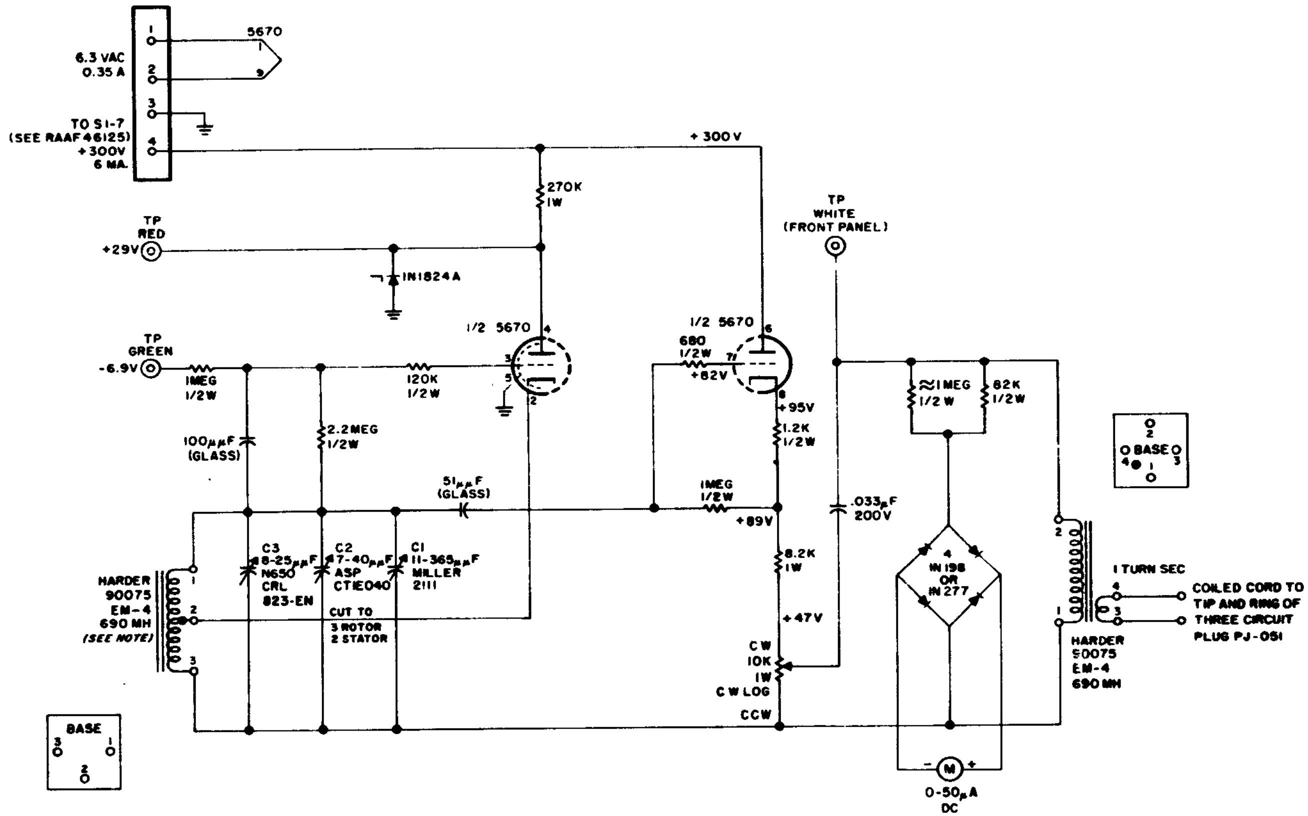
The frequency need not be exact (±1 c/s), since phase holding is not necessary for calibration, but the amplitude must be known and repeatable.

The oscillator uses LC tuning in a Hartley configuration and covers a frequency range of 9.2 to 16.2 kc/s. The tube is operated at a low value of plate voltage stabilized by a Zener diode. No temperature compensation is necessary since the frequency is monitored during the calibration period. C1 provides coarse tuning; C2 provides fine or vernier tuning and C3 is used for setting the high frequency end of the dial.

The second half of the tube, connected as a cathode follower, is used for isolation and power gain. An output level control in the cathode circuit is provided to set the required calibration voltage. The output level control directly feeds the output transformer. Metering is accomplished across the primary winding. The output transformer has a turns ratio of approximately 2200 to 1 and gives an output impedance of 0.001 ohm for the worst setting of the level control.

The generator impedance is considerably increased by the output cable, plug and wiring but still does not cause a measurable effect when the secondary winding is inserted in the first tuned circuit of the AN/URN-18(XN-1).

The output meter calibration is unimportant since, during the over-all calibration, a number is recorded for use in each individual installation.




NOTE:
TERMINAL 2 IS THE CENTER TAP. APPROXIMATELY 200 TURNS REMOVED BETWEEN TERMINALS 2 AND 3. ADJUST FOR PROPER TUNING RANGE (9.2 KC/S TO 16.2 KC/S) OF C1 WITH C2 AND C3 AT HALF CAPACITY. ADJUST INDIVIDUALLY, IN THE CIRCUIT, SINCE ALL C1 CAPACITORS ARE A LITTLE DIFFERENT.
IN SOME OSCILLATORS AN ADDITIONAL SMALL GLASS CAPACITOR IS ADDED ACROSS TERMINALS 1 AND 3 TO CORRECT THE TUNING RANGE.

*Figure 12. Schematic diagram of calibration oscillator.*

# CALIBRATION PROCEDURE

The antenna used on shore-based sites and on surface ships is a vertical whip 20 to 35 feet long. Since the environment of such an antenna has a marked effect on its effective height, each installation must receive an individual calibration. On shore installations this is usually not difficult, since the antenna may be located on the basis of a field survey, in a clear area with a good ground system and a minimum of field-distorting structures. At locations near enough to a transmitting station it is only necessary to measure the field strength using conventional RFI equipment. Calibration on surface ship installations can be impossible because of whip antenna location. If the high point of the ship can be used for the base of the antenna and this point is clear of all other antennas or rigging, it may be reasonable to assume that the field received by the whip and the existing field can be correlated. Lack of opportunity to conduct experiments on ship installations under controlled conditions precludes any accurate statement regarding calibration and azimuthal distortion of the received signal.

Vertical whips used on shore installations should be rechecked to prove their calibration until it can be shown that seasonal changes have little or a known effect. The whip, being a high-impedance device, is affected by dirt on its insulator and by environmental conditions such as humidity and other local weather phenomena. The sensitivity to local conditions can be compensated for in the periodic (twice daily or oftener) calibration procedure, by injecting a known local signal into the first tuned circuit, thus simulating the voltage induced by the antenna; the gain can then be adjusted to compensate for leakages which reduce the Q of the first stage.

Installations at shore-based sites, so distant from a transmitting site that the steady-state intensity may not be measured using conventional RFI equipment, require special equipment and carefully controlled measurements well within the near zone. This method requires that a local signal be radiated as strong as necessary for the magnetic field to be indicated, well above the ambient noise level, on a conventional RFI meter using a loop antenna. With portable equipment, this is very difficult to accomplish at distances greater than 200 meters.

Calculations at NEL show that from a very short transmitting antenna, at a frequency of 10.2 kc/s, the ratio of electric to magnetic fields varies from 47:1 to 23.5:1 at distances between 100 and 200 meters. On the basis of these calculations, a local signal can be transmitted, measured by an RFI meter using a loop antenna, ratio corrections applied, and the whip antenna calibrated. Extreme care must be used in determining whether field distortions are present and in measuring distances and fields. Since there are so many chances for error, it is not recommended that this method of calibration be depended on for an accuracy of better than ±3 db.

At installations that have been impossible to calibrate for absolute values, some useful information may be taken regarding seasonal, diurnal, and hourly variations in field strength.

# CONCLUSIONS

The field strength recorder which was developed operates satisfactorily as a superheterodyne receiver with three channels of manual gain control, an i-f filter with a narrow bandwidth, a coherent detector, and three recorders (one for each Omega station). The recorder, in its present design, is adequate for measuring the radio field coverage of the Omega system.

# APPENDIX: SAMPLE FIELD INTENSITY RECORDINGS AT 10.2 KC/S

The Field Strength Recorder described in the main body of the report was used to measure the coverage of the three Omega stations. Measurements were made at selected receiving sites both within the triad of the Omega transmitting stations and around the periphery of their anticipated operating area. This Appendix presents a small sample of the data which were taken.

Table 1A lists the sites from which data have been collected. Of the four sites on the Island of Oahu, Hawaii, three have shown good agreement on distant and local signals and so may be considered as one location. The fourth site, at MCAS, Kaneohe, is being prepared for operation. When it is completed, field intensity measurements for the Hawaiian area will be made there. The site at Thule, Greenland, is well outside the expected operating area of the three Omega stations. Because of its location, and other circumstances, equipment calibration was very difficult; the recording accuracy at Thule is limited to ± 3 db. At all of the other sites the equipment has been calibrated to an accuracy of ± 1 db.

The method by which field intensities were received and measured is described in the main body of the report. Since all three Omega stations operate sequentially, on the same frequency, and on a 24-hour schedule, simultaneous reciprocal path measurements are made over three paths.

The coherent detector technique allows linear (non-degraded) recording of signals 20 db below the noise (in a 100-c/s bandwidth). Since the Field Strength Recorder responds to signal only, within the limits just stated, no simultaneous noise recording is necessary.

Table 2A lists the Omega transmitting stations and their radiated power. Both Haiku and Balboa hold their

Table A-1. Receiving sites for Omega field intensity recordings.

| RECEIVING SITE | LOCATION (NAD, 1927) | PATH LENGTH (km) to TRANSMITTERS | | COMPOSITION OF PATH, LAND-SEA (%) Land | Sea |
|---|---|---|---|---|---|
| Farfan, Canal Zone | Lat: 8° 55' 52.83" N | Balboa | 15.412 | 100 | 0 |
| | Long: 79° 35' 03.32" W | Haiku | 8447.49 | 8.5 | 91.5 |
| | | Forestport | 3849.30 | 19 | 81 |
| RADC, Rome, New York | Lat: 43° 13' 26.4" N | Balboa | 3808.68 | 19 | 81 |
| | Long: 75° 24' 36.8" W | Haiku | 7813.84 | 53 | 47 |
| | | Forestport | 35.9645 | 100 | 0 |
| Opana (CMR Site), Oahu, Hawaii | Lat: 21° 41' 21.36" N | Balboa | 8452.25 | 8.5 | 91.5 |
| | Long: 158° 00' 42.78" W | Haiku | 36.2203 | 100 | 0 |
| | | Forestport | 7828.85 | 53 | 47 |
| Makapuu Point, Oahu, Hawaii | Lat: 21° 18' 45" N | Balboa | 8418.67 | 8.5 | 91.5 |
| | Long: 157° 39' 20" W | Haiku | 21.277 | 100 | 0 |
| | | Forestport | 7827.414 | 53 | 47 |
| USNRS (R), Wahiawa Oahu, Hawaii | Lat: 21° 31' 08.3" N | Balboa | 8452.64 | 8.5 | 91.5 |
| | Long: 158° 00' 06.2" W | Haiku | 21.3119 | 100 | 0 |
| | | Forestport | 7840.17 | 53 | 47 |
| Pyramid Rock (MCAS), Kaneohe, Oahu, Hawaii | Lat: 21° 27' 51" N | Balboa | 8428.971 | 8.5 | 91.5 |
| | Long: 157° 46' 05" W | Haiku | 9.218 | 59 | 41 |
| | | Forestport | 7825.543 | 53 | 47 |
| Thule AFB, Greenland | Lat: 76° 30' 46" N | Balboa | 7523.5024 | 58 | 42 |
| | Long: 68° 42' 30" W | Haiku | 7680.8114 | 42 | 58 |
| | | Forestport | 3695.9937 | 79 | 21 |
| Arctic Research Lab., Barrow, Alaska | Lat: 71° 18' 25" N | Balboa | 8595.7058 | 73 | 27 |
| | Long: 156° 44' 29" W | Haiku | 5547.0120 | 27 | 73 |
| | | Forestport | 5212.7723 | 100 | 0 |
| University of Alaska Geophysical Institute College, Alaska | Lat: 64° 51' 26" N | Balboa | 8075.4888 | 70 | 30 |
| | Long: 147° 49' 17" W | Haiku | 4883.0383 | 10 | 90 |
| | | Forestport | 4954.4772 | 100 | 0 |
| NAS, Seaplane Base, Whidbey Island, Washington | Lat: 48° 16' 52" N | Balboa | 5916.5008 | 54 | 46 |
| | Long: 122° 37' 17" W | Haiku | 4321.7349 | 2 | 98 |
| | | Forestport | 3670.2321 | 100 | 0 |
| USNEL, Bldg. 33, San Diego, California | Lat: 32° 42' 28.65" N | Balboa | 4666.46 | 73 | 27 |
| | Long: 117° 14' 42.27" W | Haiku | 4188.06 | 0 | 100 |
| | | Forestport | 3840.495 | 100 | 0 |

Table A-2. Description of Omega transmitting stations.

| STATION | LOCATION | RADIATED POWER |
|---|---|---|
| Haiku, Oahu, Hawaii | Lat: 21°24'28.67" N<br>Long: 157°50'0.80" W | 4 kw |
| Balboa (Summit) C. Z. | Lat: 9°03'14.67" N<br>Long: 79°38'53.22" W | 1.4 kw |
| Forestport, N. Y. | Lat: 43°26'42" N<br>Long: 75°05'10"W | 5-165 watts |

radiated power constant to approximately ± 0.5 db. Because of a rather poor antenna and severe weather conditions, especially during the winter months, the radiated power from Forestport varies over a wide range. Typically, the station is run at the highest power acceptable by the voltage limitations of the antenna. Corrections to 1 kw radiated power are made from data collected by the local (Rome, New York) Field Strength Recorder.

Figures A1-A36 are graphs of some of the field intensity recordings. A few have been normalized to a standard radiated power of 1 kilowatt, and are so indicated. The other graphs were plotted as the signals were received and may be corrected by reference to the appropriate radiated power as shown in table 2.

Measurements at some of the installations were made on a short-time basis with no plans to return for additional data. The Field Strength Recorders near the three transmitting sites are permanent installations and will remain, either at the same locations or nearby, for the duration of the Omega investigations. Therefore, of the six Field Strength Recorders which were built, only three are available for locations other than transmitting sites. The locations of these, and the duration of operation, are predicated on geography, geometry of the system, and availability of operating personnel. These factors will change as operational needs dictate.

No conclusions will be drawn at this time regarding the measurements which have been made. The recordings are furnished only to give a small sample of the data taken. The final method of processing and presenting the complete collection of data is now under study at the Navy Electronics Laboratory.

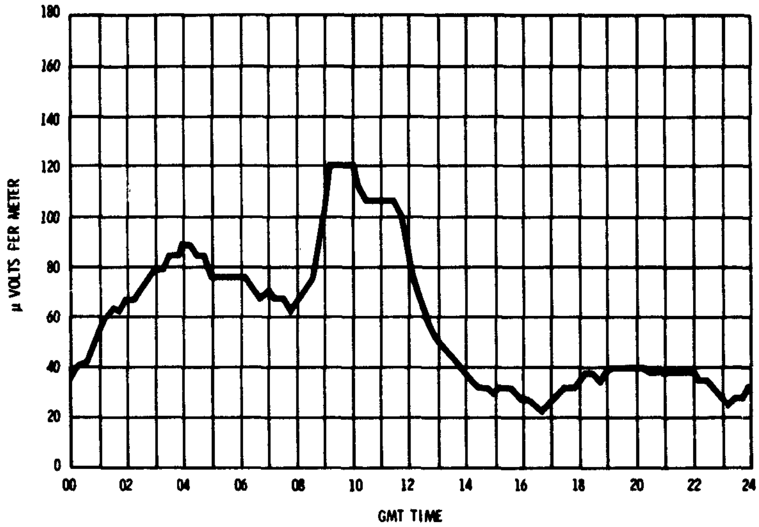



*Figure A-1. 10.2kc/s signal as received at Farfan, C. Z., from Haiku, Hawaii, 11 Dec 62. Radiated power normalized to 1 kw.*

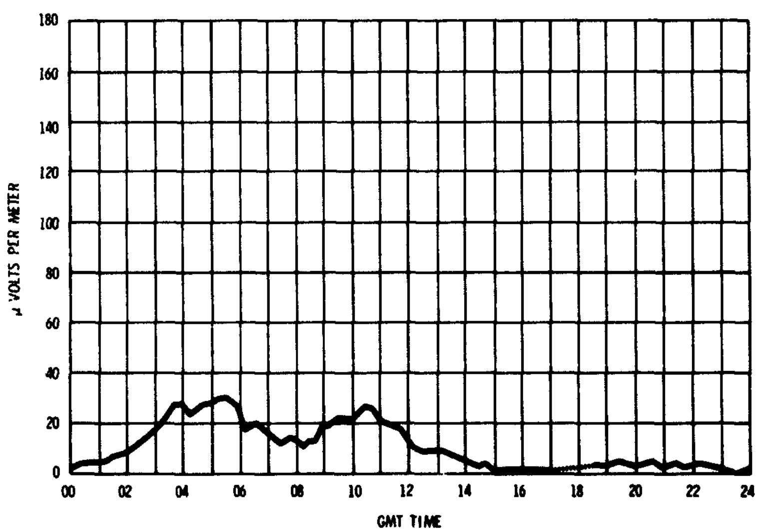



*Figure A-2. 10.2kc/s signal as received at Wahiawa, Hawaii, from Balboa, C. Z., 11 Dec 62. Radiated power normalized to 1 kw.*

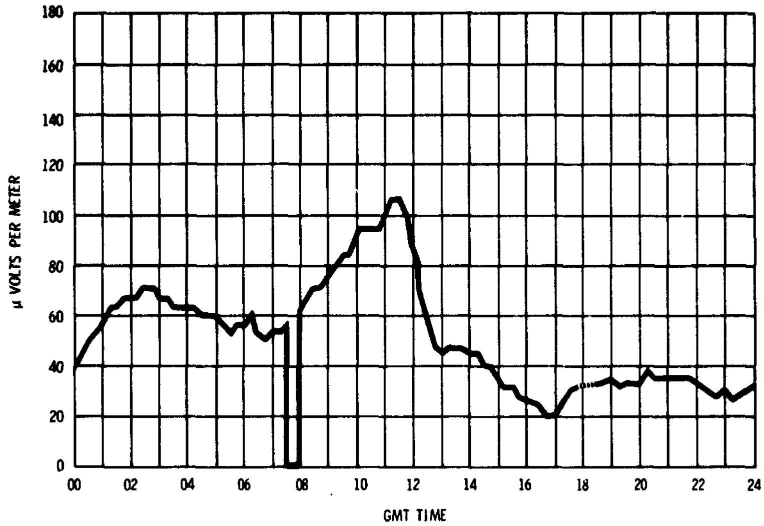



*Figure A-3. 10.2 kc/s signal as received at Farfan, C. Z., from Haiku, Hawaii, 14 Dec 62. Radiated power normalized to 1 kw.*

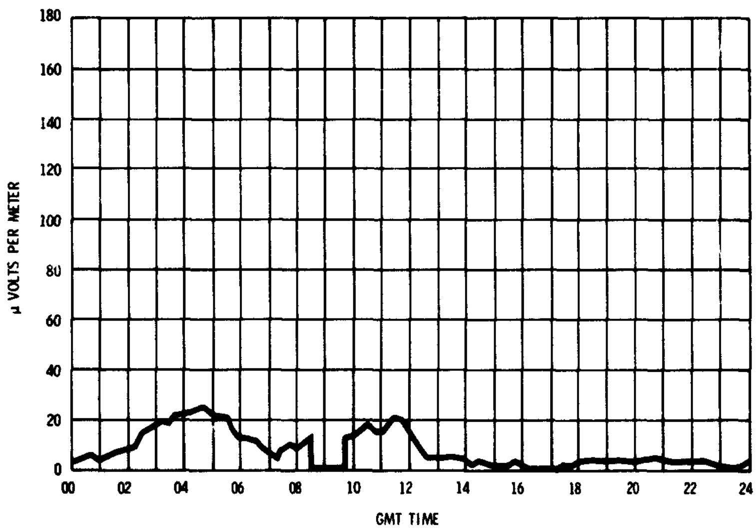



*Figure A-4. 10.2 kc/s signal as received at Wahiawa, Hawaii, from Balboa, C. Z., 14 Dec 62. Radiated power normalized to 1 kw.*


*Figure A-5. 10.2 kc/s signal as received at Farfan, C. Z., from Forestport, N. Y., 30 Nov 62. Radiated power normalized to 1 kw.*

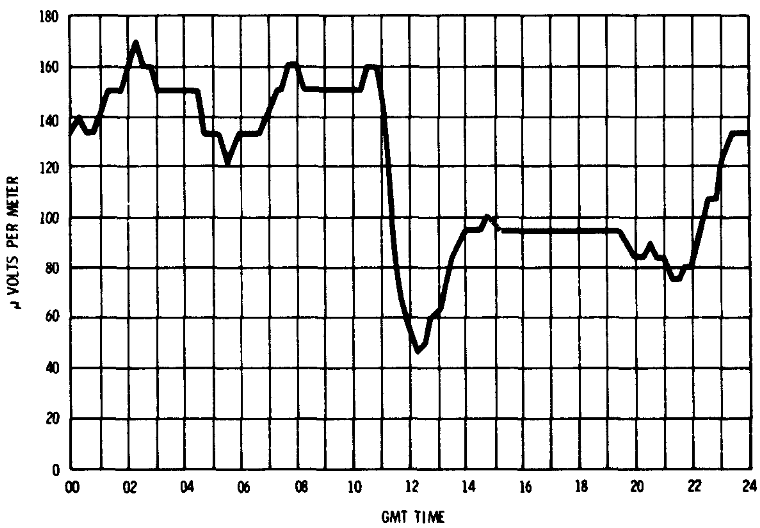



*Figure A-6. 10.2 kc/s signal as received at Rome, N. Y., from Balboa, C. Z., 30 Nov 62. Radiated power normalized to 1 kw.*

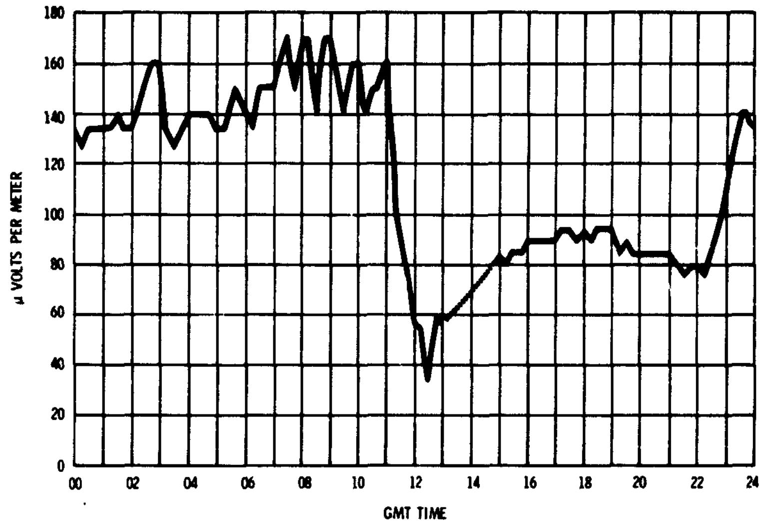



*Figure A-7. 10.2 kc/s signal as received at Farfan, C. Z., from Forestport, N. Y., 4 Dec 62. Radiated power normalized to 1 kw.*

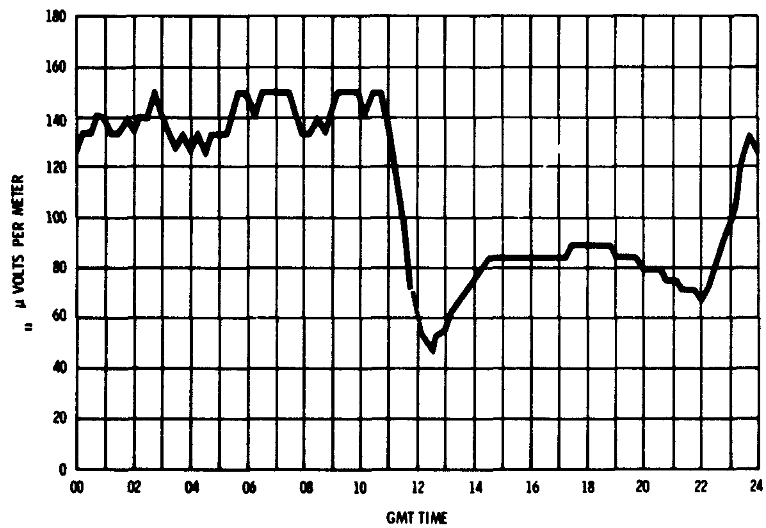



*Figure A-8. 10.2 kc/s signal as received at Rome, N. Y., from Balboa, C. Z., 4 Dec 62. Radiated power normalized to 1 kw.*

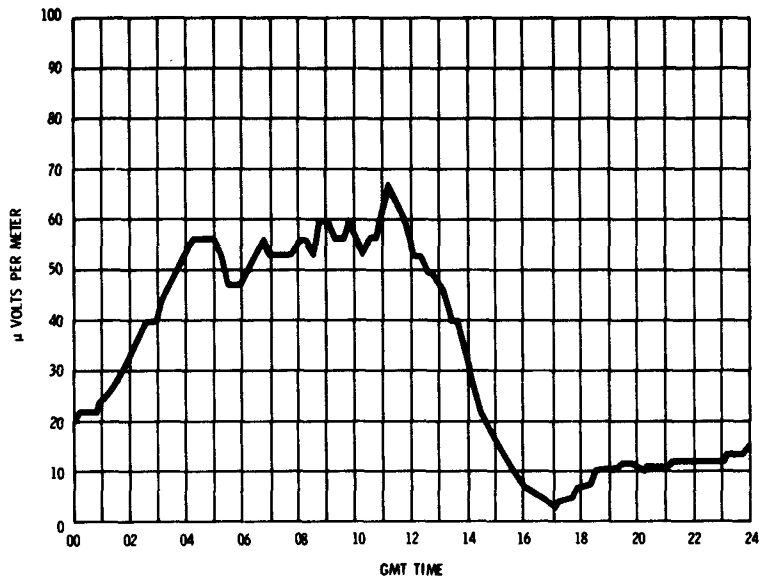



*Figure A-9. 10.2kc/s signal as received at Rome, N. Y., from Haiku, Hawaii, 15 Jan 63. Radiated power normalized to 1 kw.*

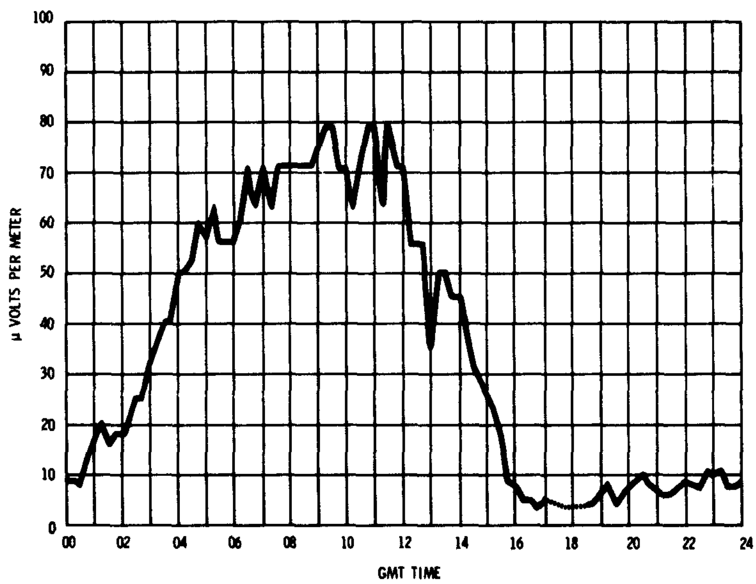



*Figure A-10. 10.2kc/s signal as received at Wahiawa, Hawaii, from Forestport, N. Y., 15 Jan 63. Radiated power normalized to 1 kw.*

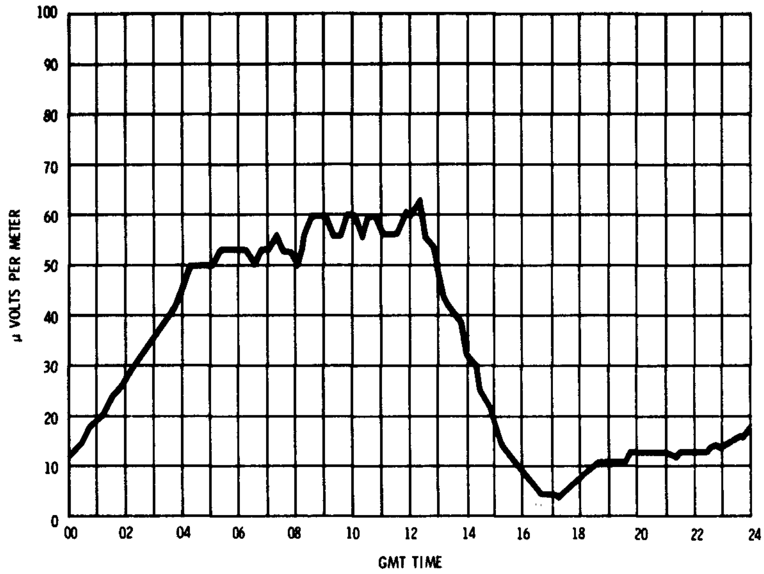



*Figure A-11. 10.2 kc/s signal as received at Rome, N. Y., from Haiku, Hawaii, 17 Jan 63. Radiated power normalized to 1 kw.*

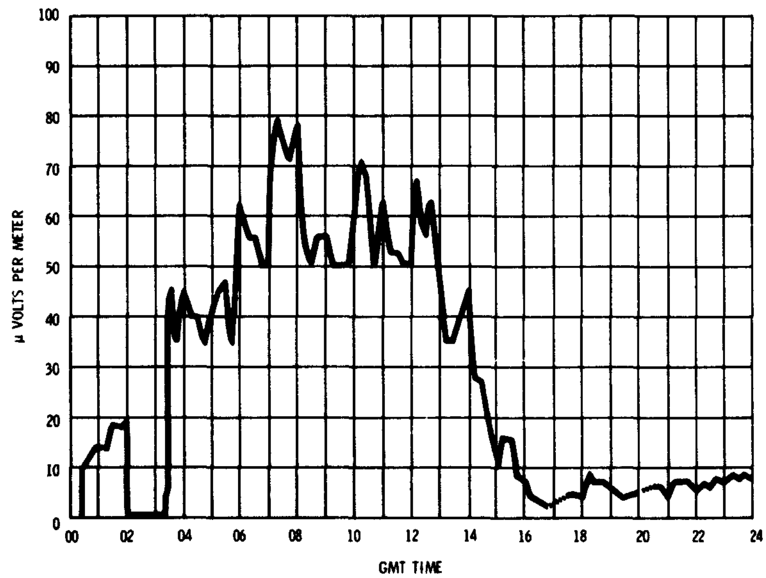



*Figure A-12. 10.2 kc/s signal as received at Wahiawa, Hawaii, from Forestport, N. Y., 17 Jan 63. Radiated power normalized to 1 kw.*

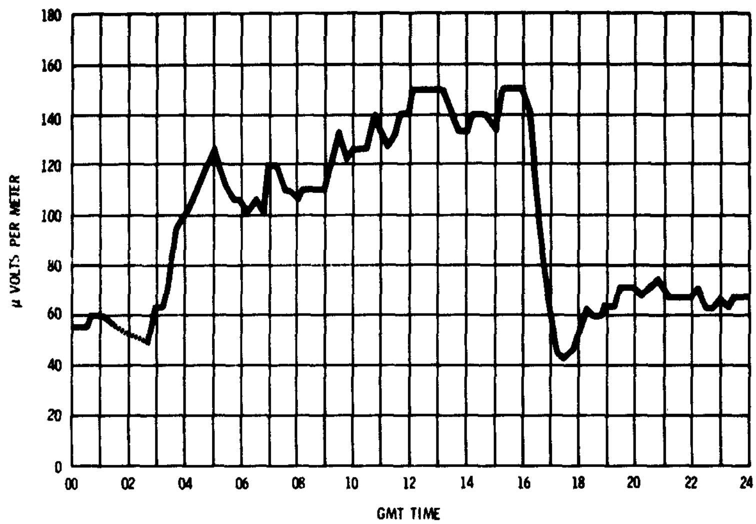



*Figure A-13. 10.2 kc/s signal as received at College, Alaska, from Haiku, Hawaii, 6 Nov 62. Radiated power normalized to 1 kw.*

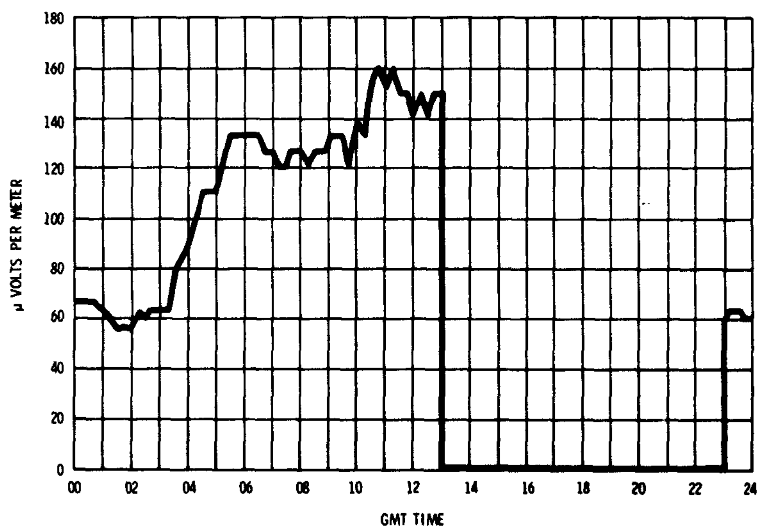



*Figure A-14. 10.2 kc/s signal as received at College, Alaska, from Haiku, Hawaii, 7 Nov 62. Radiated power normalized to 1 kw.*

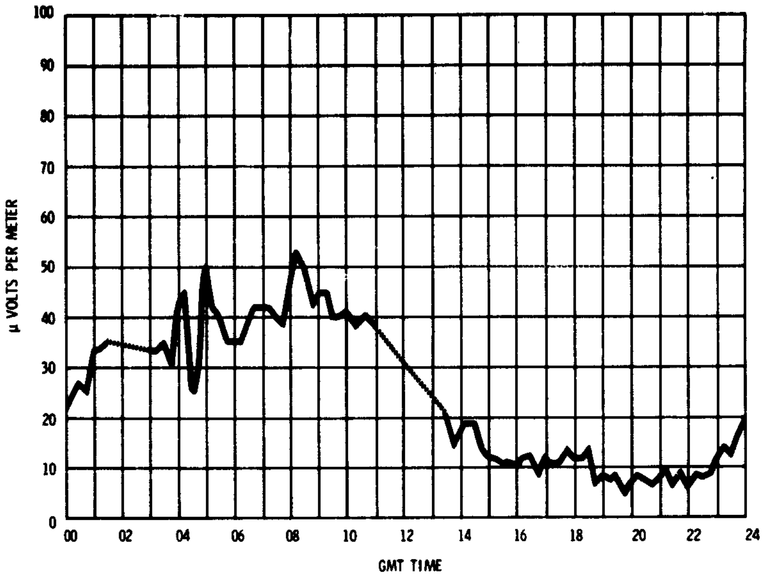



*Figure A-15. 10.2kc/s signal as received at College, Alaska, from Forestport, N. Y., 6 Nov 62. Radiated power normalized to 1 kw.*

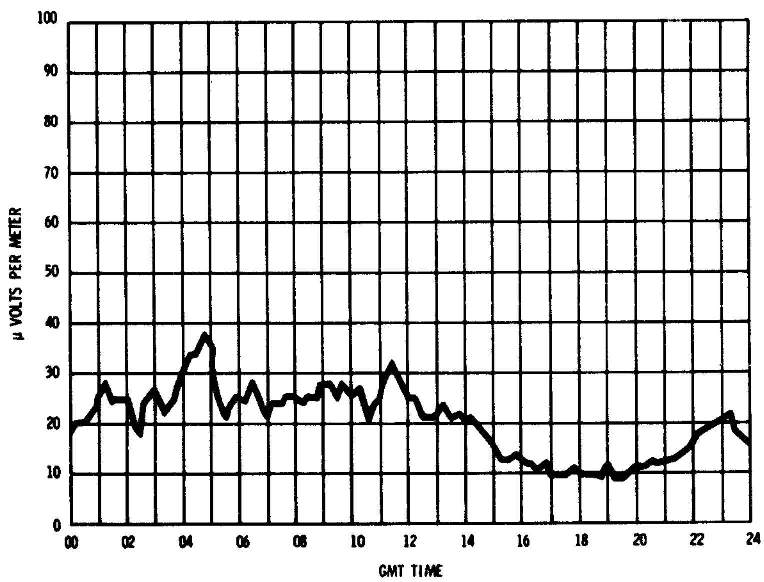



*Figure A-16. 10.2kc/s signal as received at College, Alaska, from Forestport, N.Y., 30 Nov 62. Radiated power normalized to 1 kw.*

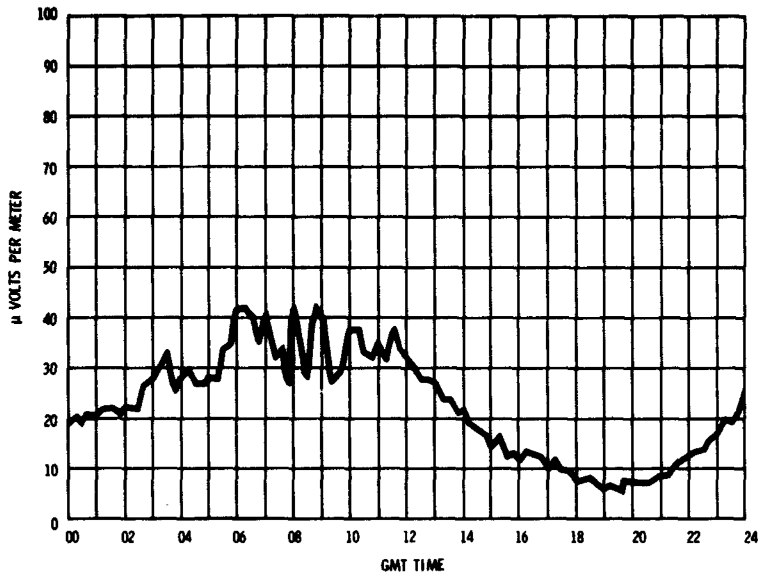



*Figure A-17. 10.2kc/s signal as received at College, Alaska, from Forestport, N.Y., 4 Dec 62. Radiated power normalized to 1 kw.*

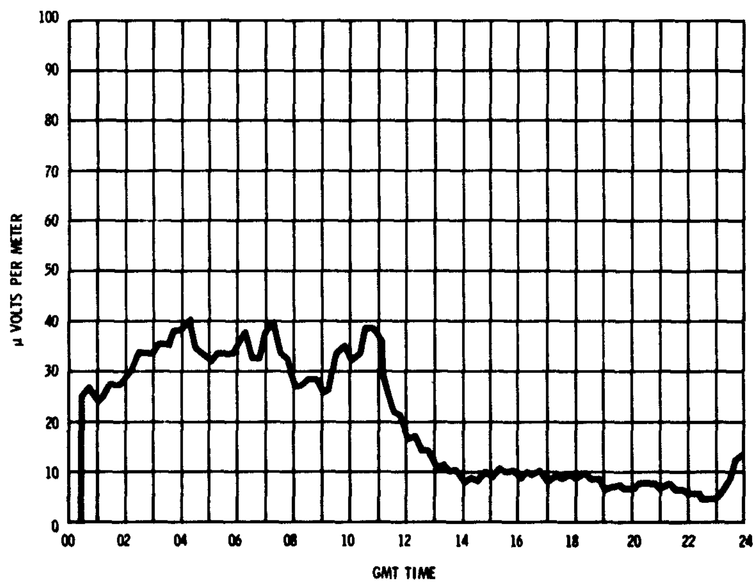



*Figure A-18. 10.2kc/s signal as received at College, Alaska, from Balboa, C. Z., 24 Nov 62. Radiated power normalized to 1 kw.*

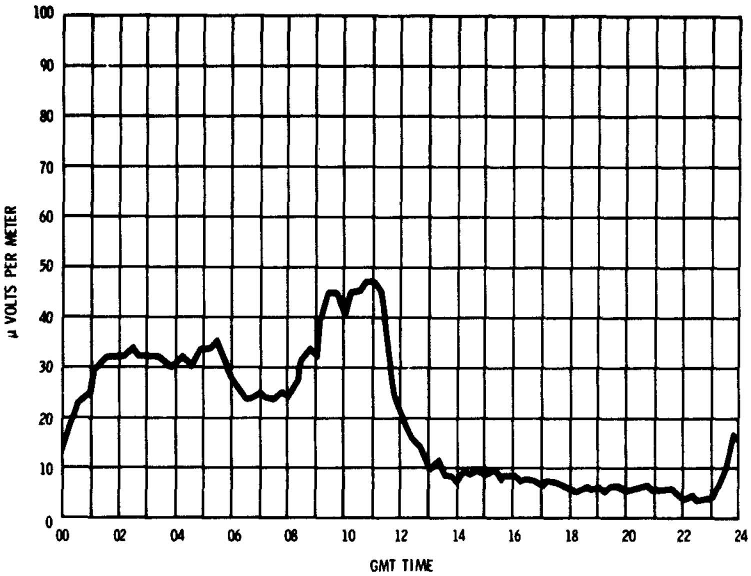



*Figure A-19. 10.2kc/s signal as received at College, Alaska, from Balboa, C. Z., 26 Nov 62. Radiated power normalized to 1 kw.*

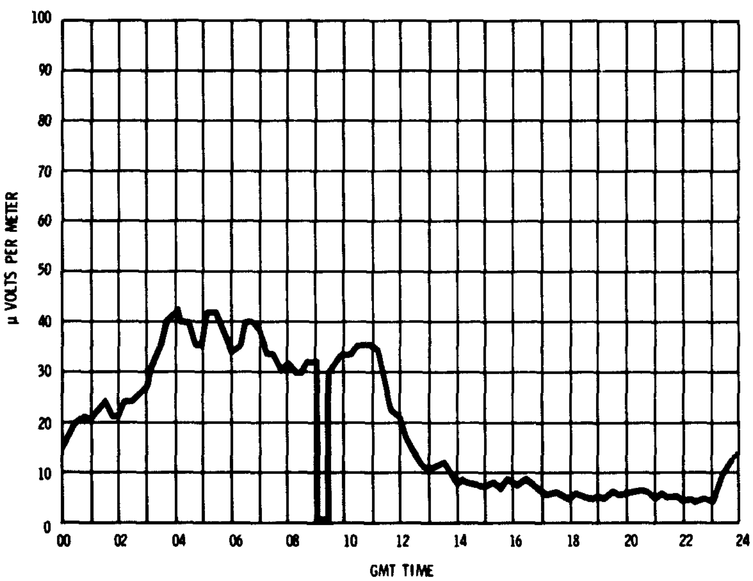



*Figure A-20. 10.2kc/s signal as received at College, Alaska, from Balboa, C. Z., 27 Nov 62. Radiated power normalized to 1 kw.*

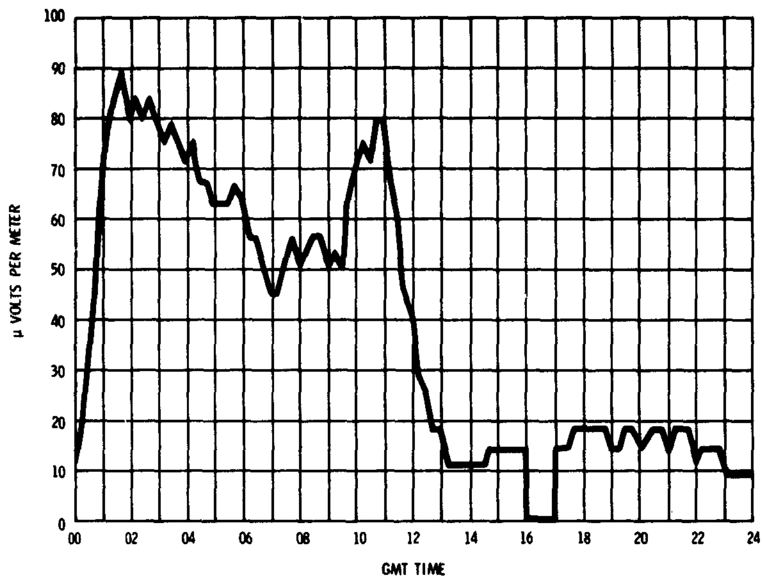



*Figure A-21. 10.2kc/s signal as received at Whidbey Island, Wash., from Balboa, C. Z., 18 Oct 62.*

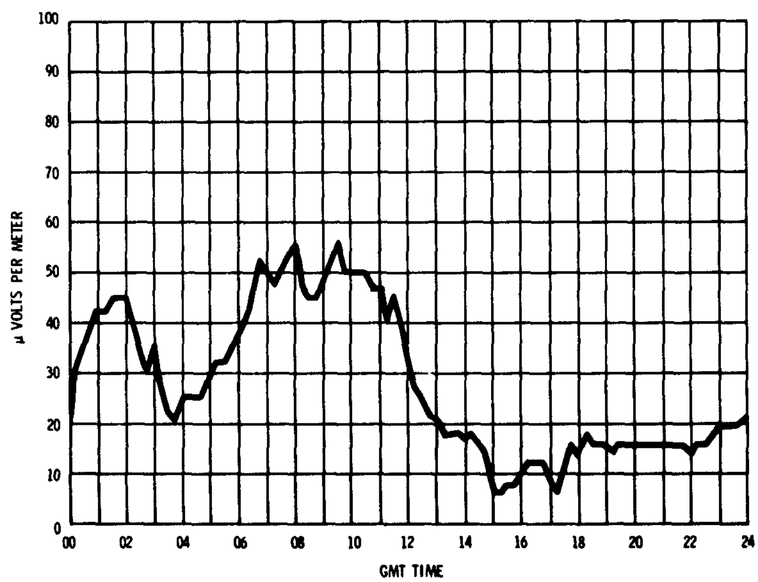



*Figure A-22. 10.2 kc/s signal as received at Whidbey Island, Wash., from Forestport, N. Y., 18 Oct 62.*

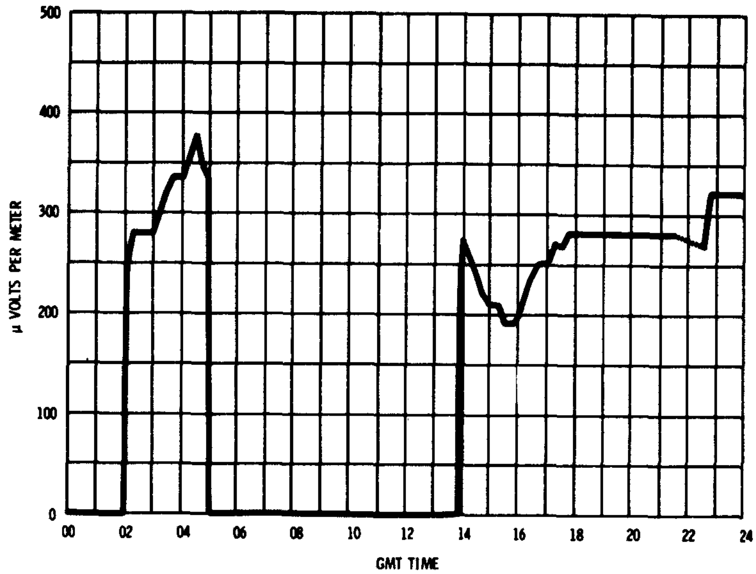



*Figure A-23. 10.2kc/s signal as received at NEL, San Diego, from Haiku, Hawaii, 26 Apr 62.*

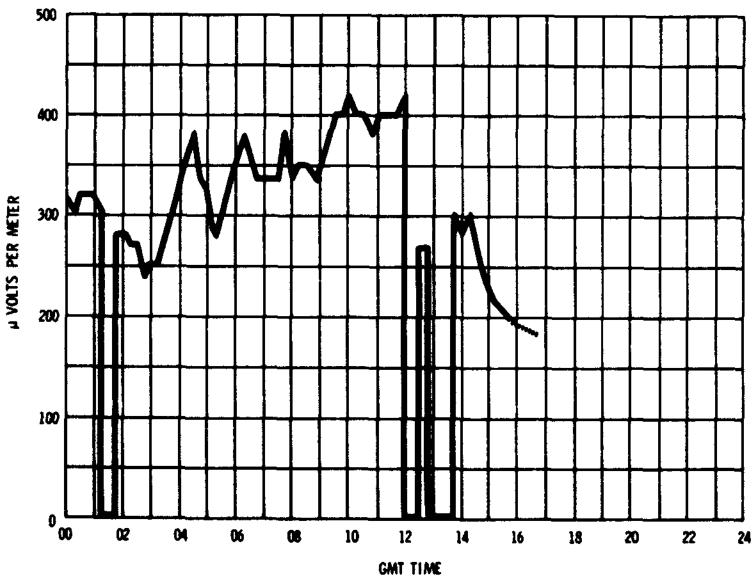



*Figure A-24. 10.2 kc/s signal as received at NEL, San Diego, from Haiku, Hawaii, 27 Apr 62.*

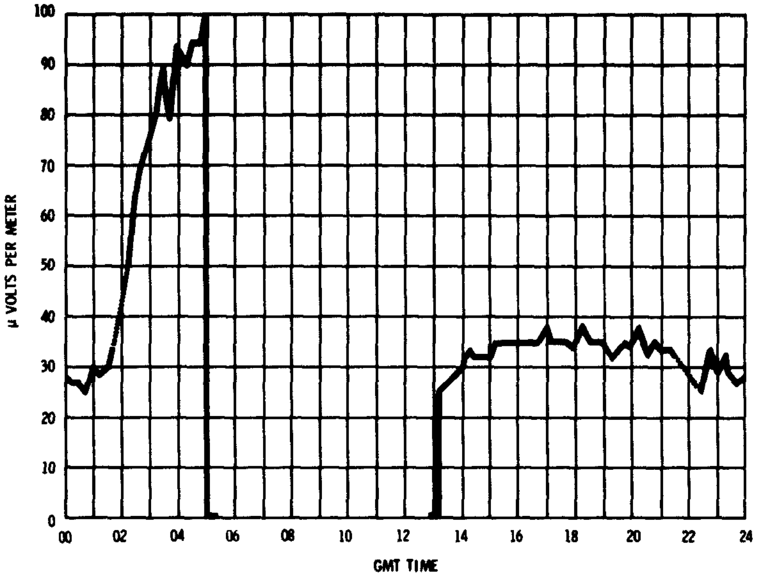



*Figure A-25. 10.2 kc/s signal as received at NEL, San Diego, from Forestport, N. Y., 26 Apr 62.*


*Figure A-26. 10.2 kc/s signal as received at NEL, San Diego, from Forestport, N. Y., 27 Apr 62.*

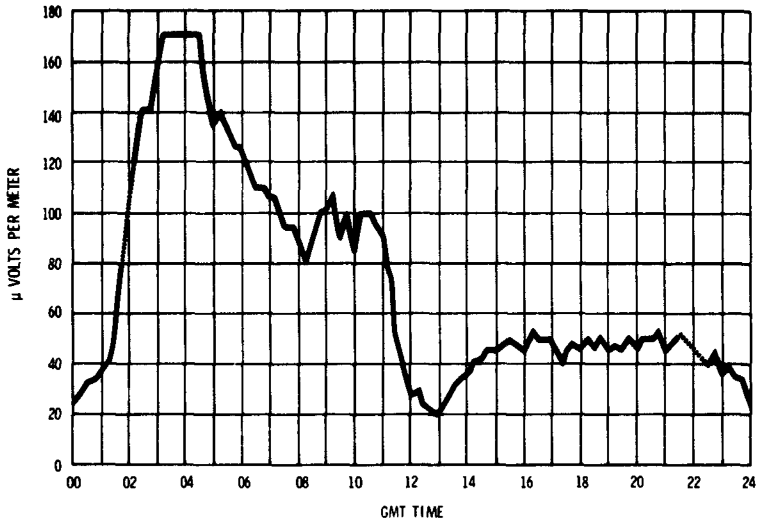



*Figure A-27. 10.2 kc/s signal as rcceived at NEL, San Diego, from Balboa, C. Z., 26 Apr 62.*

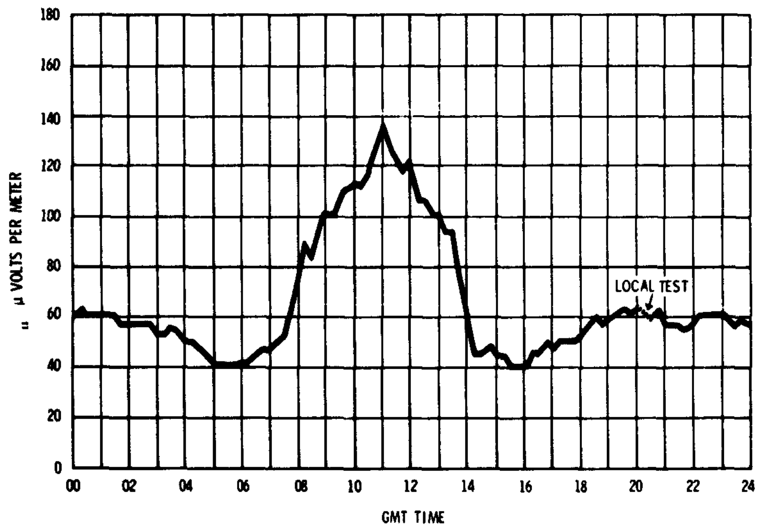



*Figure A-28. 10.2 kc/s signal as received at Barrow, Alaska, from Haiku, Hawaii, 29 June 62.*

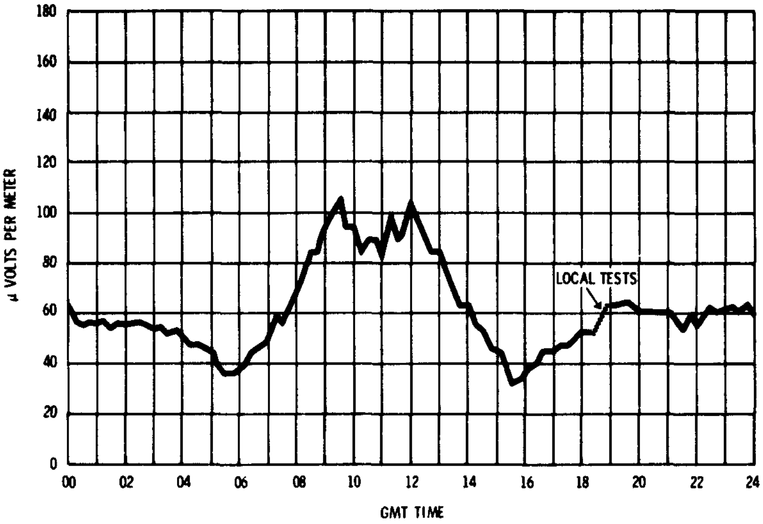



*Figure A-29. 10.2 kc/s signal as received at Barrow, Alaska, from Haiku, Hawaii, 30 June 62.*

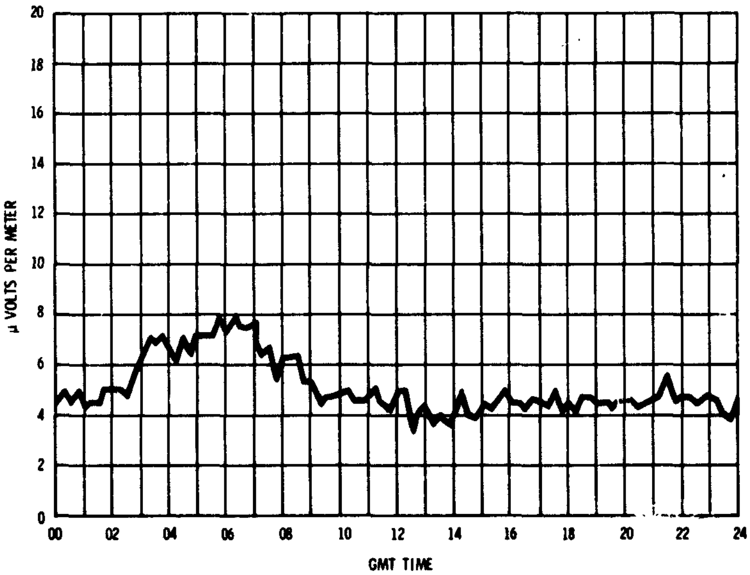



*Figure A-30. 10.2 kc/s signal as received at Barrow, Alaska, from Forestport, N. Y., 29 June 62.*

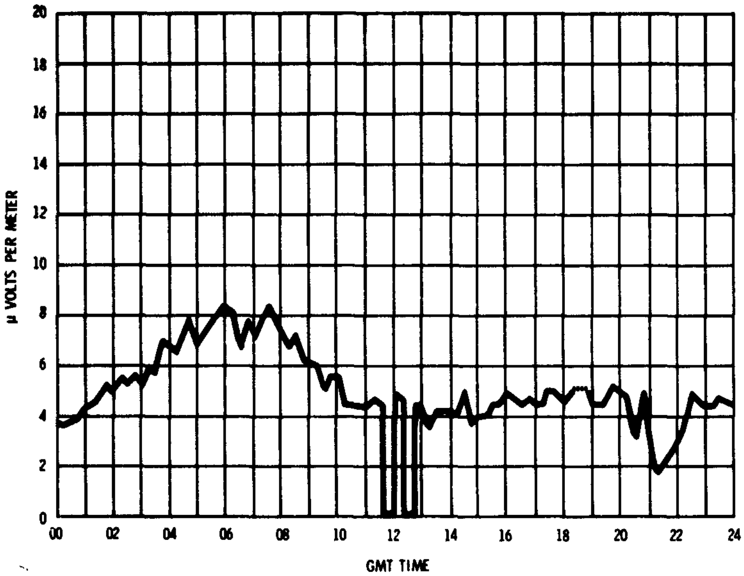



*Figure A-31. 10.2 kc/s signal as received at Barrow, Alaska, from Forestport, N. Y., 30 June 62.*

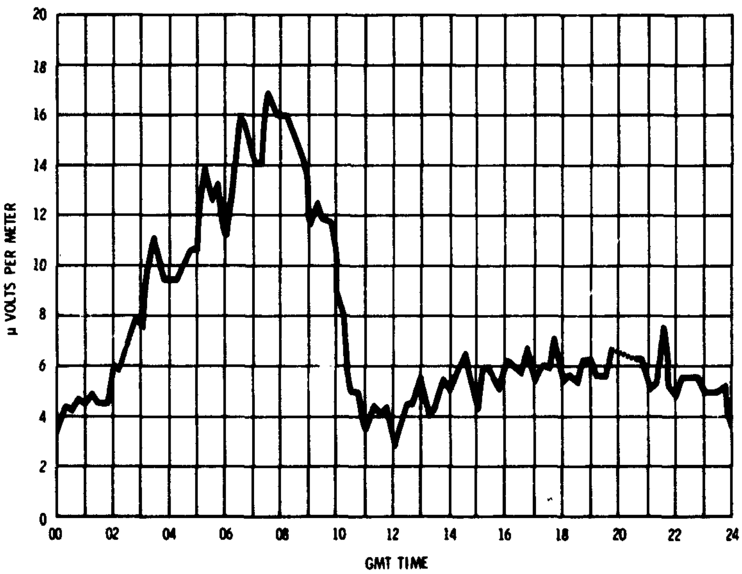



*Figure A-32. 10.2 kc/s signal as received at Barrow, Alaska, from Balboa, C. Z., 29 June 62.*

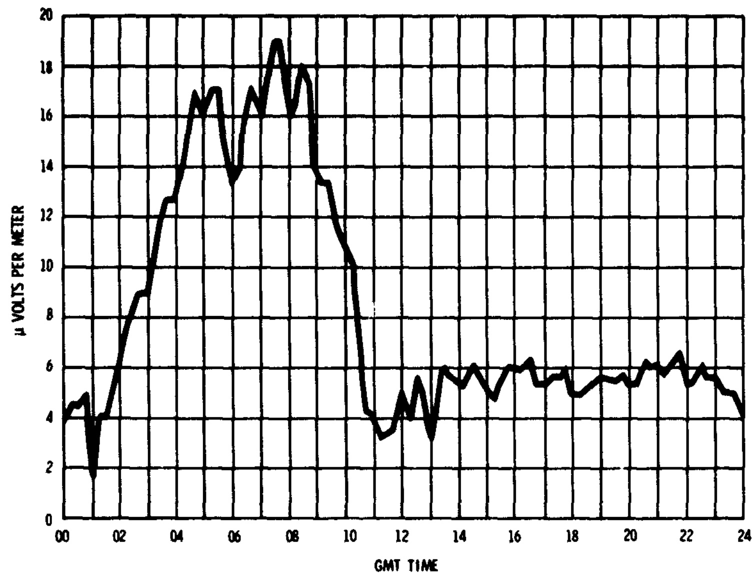



*Figure A-33. 10.2 kc/s signal as received at Barrow, Alaska, from Balboa, C. Z., 30 June 62.*

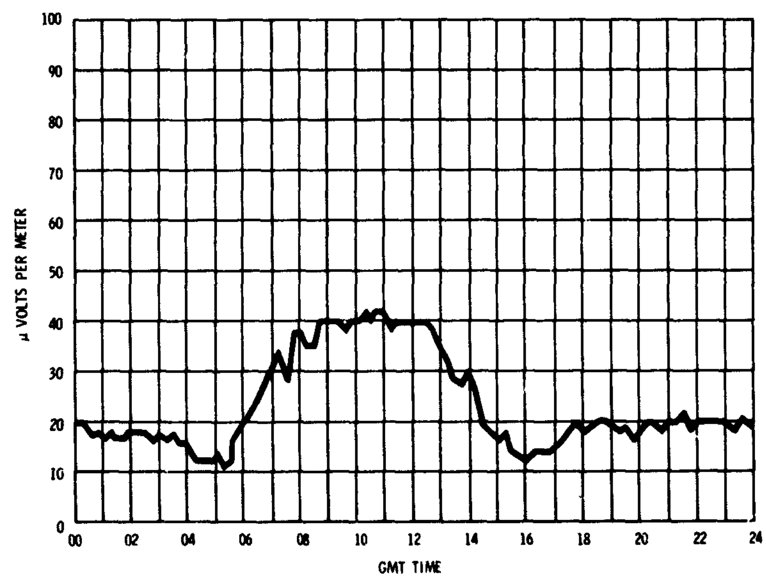



*Figure A-34. 10.2 kc/s signal as received at Thule, Greenland, from Haiku, Hawaii, 31 July 62.*

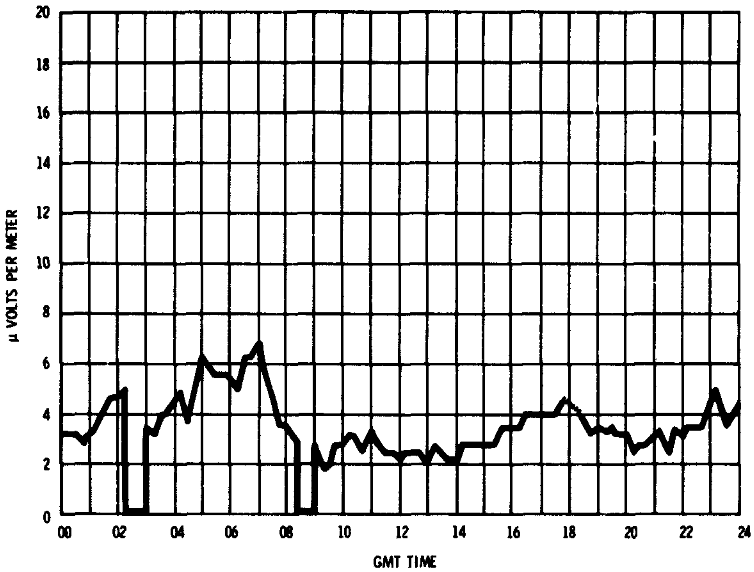



*Figure A-35. 10.2 kc/s signal as received at Thule, Greenland, from Forestport, N. Y., 31 July 62.*

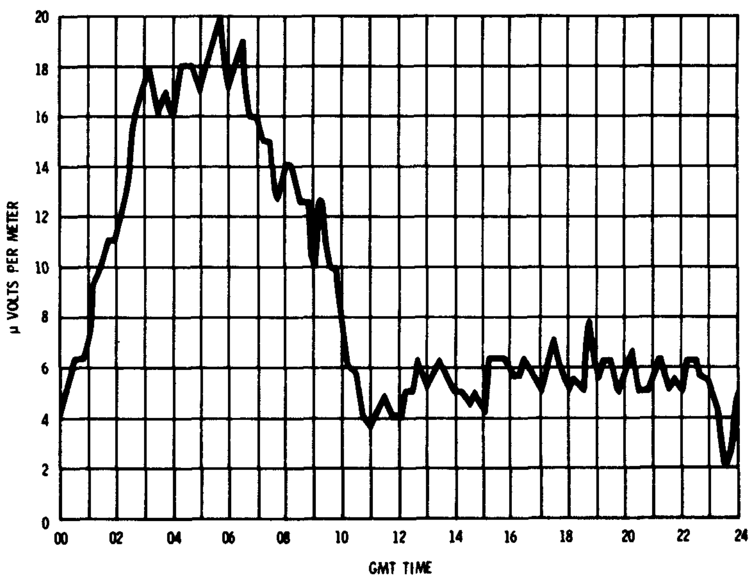



*Figure A-36. 10.2 kc/s signal as received at Thule, Greenland, from Balboa, C. Z., 31 July 62.*

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1. Omega
2. Field strength meters

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